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No. 226

Contribution from the Bureau of Entomology, L. O. Howard, Chief.
May 27, 1915.

PROFESSIONAL PAPER.

THE VERBENA BUD MOTH.

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(In cooperation with the Virginia Truck Experiment Station, Norfolk, Va.)

CONTENTS.

INTRODUCTION AND HISTORY.

During the fall of 1913 a bed of ornamental snapdragon (Antirrhinum) at the Virginia truck experiment station, Norfolk, Va., was found to be infested by the larvæ of a bud moth. The adults were reared and identified as *Olethreutes hebesana* Walk., or the verbena bud moth. Although long ago recognized as injurious to certain ornamentals, it appears that no attempt had been made to determine its life history, with the exception of a short note regarding the habits of the larva and a description of the different stages. Since 1868, at which date it was fully described, an interval of over 46 years has elapsed and but little has been published concerning it.

The first intimation we have of this insect as a pest occurs in a letter by A. S. Fuller, forwarded in 1868 with specimens to C. V. Riley, then State entomologist of Missouri. Riley reared the adults from the seeds of Tigridia and later identified the moth as an undescribed species belonging to the tortricid genus Penthina. In honor of the discoverer Riley named the species *fullerea*. At about the same time two other workers independently discovered the same insect doing injury to flowering plants. Mrs. Mary Treat found it exceedingly

[1] This term is used in its broadest sense and includes all vegetables, and in addition ornamental plants.—F. H. C.

NOTE.—This bulletin gives the life history of the verbena bud moth, its food plants, and methods for its control.

injurious to verbena and sent specimens to Riley for identification, while Miss M. E. Murtfeldt found the insect injuring Antirrhinum at Kirkwood, Mo.

The species was later observed and collected by entomologists in various sections of the country, and notices to that effect appear scattered through our literature.

NAME AND SYNONYMY.

Popularly this moth has only one name, the "verbena bud moth," given it by Mrs. Mary Treat in 1869 from the plant upon which it was found feeding. Scientifically, however, it has in its brief history been known by several names and has been shifted from one genus to another. Both Fernald and Walsingham have listed the species under the genus Penthina. Later it has been listed by H. G. Dyar and J. B. Smith under the genus Olethreutes. As it now stands we have the following synonymy:

Olethreutes hebesana Walk., Dyar, 1902.
Sciaphila hebesana Walk., 1863.
Carpocapsa inexpertana Walk., 1863.
Sericoris fœdana Clem., 1865.
Penthina fullerea Riley, 1868.
Penthina hebesana Wlsm., 1879.

DISTRIBUTION.

Apparently the verbena bud moth is distributed locally at least through the eastern part of the United States. It is evidently a native American species and has been collected and found injurious in Maine, Massachusetts, New York, New Jersey, Pennsylvania, Virginia, Texas, Kansas, Indiana, and California, and is also reported from Canada.

FOOD PLANTS.

So far as known this species has confined its injuries solely to flowering plants. It has been reared from and found injurious on the following food plants: Tiger flower (*Tigridia pavonia*), snapdragon (*Antirrhinum* spp.), flag (*Iris* spp.), hedge nettle (*Stachys palustris*), mullein (*Verbascum thapsus*), verbena (*Verbena* spp.), closed gentian (*Gentiana andrewsii*), false foxglove (*Dasystoma flava*).

According to the records in the Bureau of Entomology it has several times been reared from the stems of *Tigridia pavonia* and was injurious to verbenas on the Department of Agriculture grounds in Washington, where it fed upon the flower heads, webbing a number of seed capsules together to feed upon the young and undeveloped seeds. The heads of verbena are probably not its natural habitat, since it is necessary to web them together. Among other food plants in the records of the Bureau of Entomology are the closed gentian (*Gentiana andrewsii*) and false foxglove (*Dasystoma flava*). It has been found to feed in the dry seed pods of both these species, which may be included among its wild food plants.

THE MOTH.

Mr. C. H. Popenoe found the pods of mullein literally peppered by the work of this insect in Kansas and Indiana and suggests that mullein was probably the original food plant.

DESCRIPTION.

The adult of *Olethreutes hebesana* is a small dark-brown moth (Pl. I, *b*) of the usual tortricid type, with a wing expanse of about one-half inch. A technical description, including the markings, from specimens before the writer, follows:

Alar expanse, 0.50 inch; length, 0.23 inch. Head with buff-brown tufts; eyes and palpi at apices somewhat darker, antennæ short (one-third length of forewing), filiform and simple in both sexes. Thorax with the shoulder pieces and dorsal tuft uniform buff-brown. Abdomen more gray. Forewings silvery gray, with metallic blue reflections more or less intense; the lighter parts carneous, with a silvery luster; and the whole intricately shaded with dark vandyke brown. The light is mostly reflected from the beautifully marked edges of the scales, which are transversely imbicated. There are three principal dark-brown marks, namely, one broad and irregular, crossing the wing a little beyond the middle and containing a more or less complete pale ring on the posterior border just within the anterior median cell; another, subobsolete, opposite, on its inner border. Between this transverse band and the base is a smaller, irregular, brown mark, not extending to the inner margin, and between the pale ring above described and the apex of the wing a third conspicuous brown mark, not extending more than one-third the width of the wing. Each of these dark marks is relieved by a pale border, and between them the brown, blue, and flesh color are intricately mixed. Apex of wing rounded; posterior border dark, with a series of eight or nine more or less distinct rust-brown angular spots, just inside, the two largest being costal; fringes dark brown, with a deep-blue gloss. Hind wings light brown, this color becoming deeper around the posterior margin; fringes lighter. Whole undersurface of a uniform leaden brown, that of forewings somewhat darkest and showing costal marks. No sexual difference is noted except in the narrower and less pointed male abdomen.

Following are the original descriptions of the larva and pupa, from the writings of Dr. C. V. Riley:

THE LARVA.

Penthina Fullerea.—Average length exactly half an inch; general color of a uniform dirty carneous, frequently inclining to yellow and to green; two wrinkles on each segment; head jet-black, without a spot or shade; cervical shield also black, and occupying the whole surface of segment one; piliferous spots in the normal position, but scarcely observable, even with a lens, other than by the hairs proceeding from them; feet, legs, and venter of the same color as upper surface. (Fig. 1.)

THE PUPA.

The chrysalis (Pl. I, *e*).—Average length, 0.25 inch; of the usual form, with a distinct row of teeth above, on the anterior portion of each segment, and a few minute bristles at the extremity and along the sides. It is formed within a silken cocoon, constructed in one of the three tubes of the seed, and forces itself halfway out at one side when the moth is about to emerge. (Pl. II, *b;* Pl. III.)

THE EGG.

The egg and newly hatched larva have not heretofore been described. The author's description of the egg follows:

The egg.—The egg is oval with the outline somewhat irregular; long diameter, 0.45 mm., shorter diameter, 0.30. It appears flat below, with the upper surface hemispherical, pitted and also granulated. In color it is usually whitish or light cream and readily distinguishable, particularly when deposited on green sepals. Later the eggs invariably turn slightly reddish, some before hatching taking on a grayish hue.

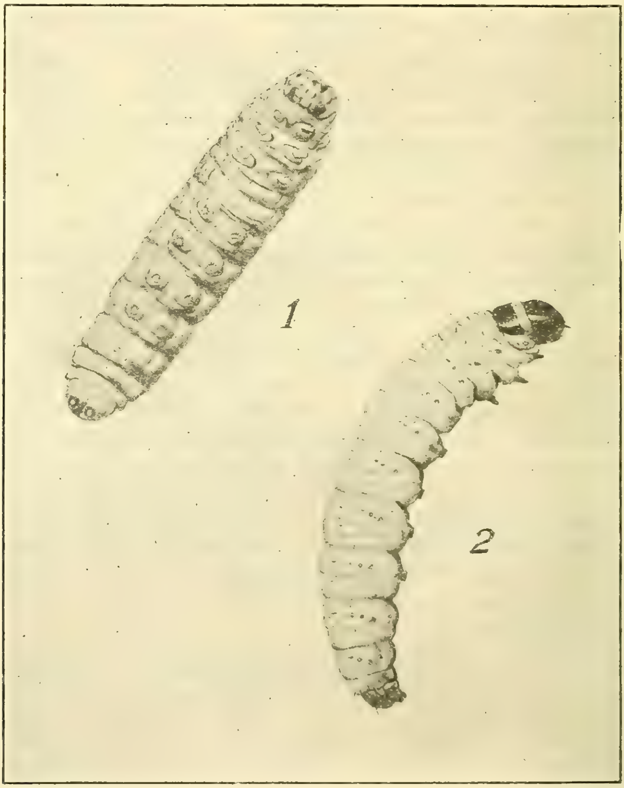
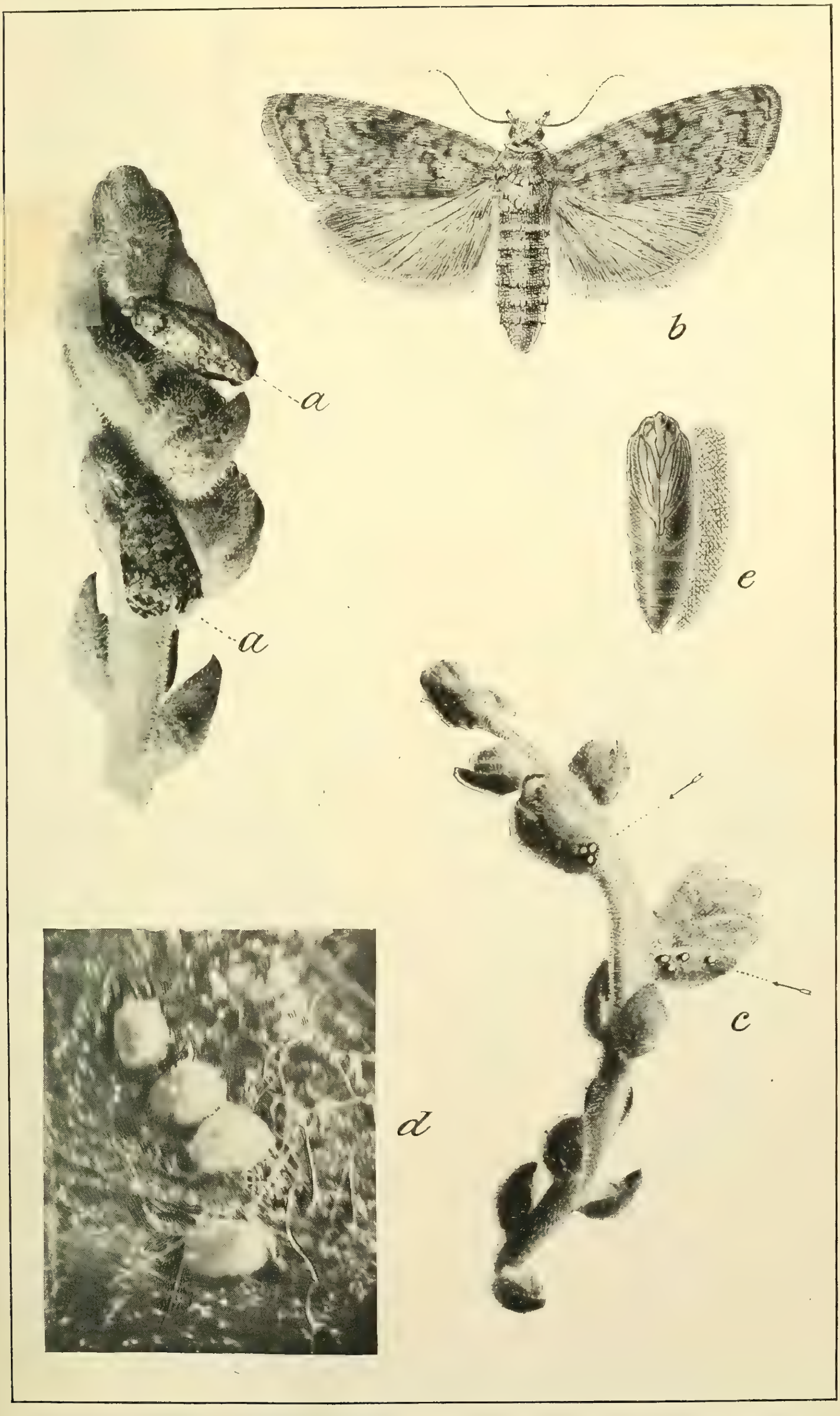


FIG. 1.—The verbena bud moth: *1*, Larva, ventral view; *2*, larva, lateral view, greatly enlarged. (Original.)

The eggs are deposited singly or sometimes in groups of from three to five on sepals of flower buds, or along the upper part of the tender flower stalk, and hatch in from 7 to 10 days. (Pl. I, *c*, *d*.)

HABITS AND SEASONAL HISTORY.

In the vicinity of Norfolk, Va., and on the grounds of the Virginia Truck Experiment Station the adults of the verbena bud moth, in 1913, began to issue on or about the last week in March. These were



a, MOTHS OVIPOSITING ON ANTIRRHINUM; *b*, FEMALE MOTH, ENLARGED; *c*, EGGS ON BUDS, ABOUT NATURAL SIZE; *d*, EGGS, ENLARGED; *e*, PUPA, ENLARGED. (ORIGINAL.)

THE VERBENA BUD MOTH (OLETHREUTES HEBESANA).

a, Flower-Stalk Showing Drooping Caused by Attack of Larvæ, Natural Size; *b*, Seed Capsules Showing Pupal Cases, and Method of Emergence of Moth, Enlarged. (Original.)

WORK OF THE VERBENA BUD MOTH ON ANTIRRHINUM.

SEED CAPSULES OF ANTIRRHINUM WHICH HAVE BEEN ATTACKED BY LARVÆ OF VERBENA BUD MOTH. EMPTY PUPAL CASES EXTRUDED. (ORIGINAL.)

WORK OF THE VERBENA BUD MOTH.

the progeny of overwintering pupæ. On March 30 moths were observed flying about a bed of snapdragon that had been severely infested the previous summer. At this date the flower buds of snapdragons were nearly ready to open.

The moths dart swiftly from plant to plant, but during bright days remain concealed among the plants. Being of a dark color and very small they are inconspicuous and not readily seen without close inspection. (Pl. I, *a*.) In the late afternoon or when the plants are disturbed the moths become active.

Oviposition occurs several days after emergence. On April 2 and 3 egg laying was observed on the flower buds. The moths invariably seek tender flower shoots upon which to oviposit, but according to observation prefer the sepals of flower buds, particularly those situated high up on the plant.

The larvæ as they emerge from the eggshells feed on the tender sepals and petals or on the flower stalk. At this time it is difficult to locate them. After feeding for a while they become more active and then direct their attacks indiscriminately. Some larvæ feed on the sepals and then bore through them, entering the flower and attacking the ovary. Others feed on the petals, stamens, and pistils of the flowers, finally reaching the ovaries. The flower stalk may be attacked by the larvæ, which first mine beneath the epidermis and feed on the juices. Later they may bore into the center of the stalk. (Pl. II, *a*.) They thus give the impression of being able to adapt themselves to many modes of feeding. The seed capsules formed by flowers which have escaped the ravages of the newly hatched larvæ are later vigorously attacked by those half grown. (Pl. III.) The larvæ that bore into the seed capsules continue to feed on the seed within, going from one seed capsule to another, until they have attained their growth. The capsules thus attacked are easily recognized by the small orifices at the base or side and by the excremental castings on the surface. In many instances two such capsules are webbed together by larvæ migrating from one capsule to another. The larvæ are easily alarmed and when disturbed have the interesting habit of thrusting out their heads, and sometimes in their alarm they wriggle out completely, dropping to the ground.

Under laboratory conditions the life cycle occupies 43 days, as follows:

Egg deposited March 2, 1913	Egg state, 8 days.
Larvæ hatched March 10, 1913	Larval state, 21 days.
Pupated March 31, 1913	Pupal state, 14 days.
Adult April 14, 1913	Life cycle, 43 days.

Less time is required during warm weather, as the following will show:

Eggs deposited July 7, 1913	Egg state, 7 days.
Larvæ hatched July 14, 1913	Larval state, 15 days.
Pupated July 31, 1913	Pupal state, 12 days.
Adult August 12, 1913	Life cycle, 34 days.

In the vicinity of Norfolk, Va., at least five or six generations are produced each year. This with the voracious and indiscriminate habit of feeding renders the species a very obnoxious pest when once it has obtained a foothold in a locality. This is particularly true where the production of seed is an object, since plants infested by this insect become worthless.

Besides undergoing all transformation within the seed capsule, the larvæ hibernate within this protection. During the winter larvæ in every stage of development, as well as pupæ, were found concealed in the seed capsules.

METHODS OF CONTROL.

Two methods of control were found effective against the larvæ of the verbena bud moth: (1) Poison spraying against the young larvæ, and (2) cutting back and destroying infested stalks.

SPRAYING.

Two poisons were employed in the spraying experiments.

(*a*) Arsenate of lead, 2 pounds to 50 gallons of water.
Fish-oil soap, 2 pounds to 50 gallons of water.

(*b*) Arsenite of zinc, 1½ pounds to 50 gallons of water.
Fish-oil soap, 2 pounds to 50 gallons of water.

The spraying was done as soon as the larvæ began to hatch and was directed toward the flower buds and young flower stalks. Subsequent investigation developed that from 85 to 90 per cent of the larvæ had been killed. A second spraying followed eight days later, owing to the fact that after the first spraying some moths were observed ovipositing.

CUTTING BACK AND DESTROYING INFESTED FLOWER STALKS.

The nature of the verbena plant is such that during the fall of the year the entire growth may be cut back and new growth will start the following year. In this way the whole brood, including all stages of the pest, is entirely eradicated. If this method is not followed in the fall, one may, in the spring of the year, cut out carefully the infested stalks, and the flower bed should be gone over several times in order to obtain those missed at the time of the first cutting.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 227

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. PROFESSIONAL PAPER August 23, 1915.

THE TOXICITY TO FUNGI OF VARIOUS OILS AND SALTS, PARTICULARLY THOSE USED IN WOOD PRESERVATION.[1]

By C. J. Humphrey, *Assistant Pathologist*, and Ruth M. Fleming, *Scientific Assistant, Office of Investigations in Forest Pathology.*

CONTENTS.

INTRODUCTION.

Within comparatively recent years the subject of wood preservation has become of paramount importance, largely resulting from the economic conditions which necessitate the utilization of timber inferior in its resistance to decay to species formerly readily obtained. The rise of wood preservation in the United States within the last two decades has been very rapid. The principal preservatives used have consisted of coal-tar creosote and zinc chlorid, either alone or in combination. Such experimental work as has been done prior to the last two or three years has been directed in large part toward perfecting the mechanical processes of injecting the preservatives into wood, with an idea of securing the greatest relative efficiency as compared with the cost involved—purely an engineering proposition based on

[1] The writers wish to thank Mr. Howard F. Weiss, Director of the Forest-Products Laboratory, Madison, Wis., for the interest displayed and suggestions offered during the progress of this work, as well as for the laboratory facilities placed at their disposal. Thanks are also due to Mr. Ernest Bateman, Chemist in Forest Products at the Forest-Products Laboratory, for all the data on chemical analyses of the different preservatives, and to Drs. R. H. True, F. D. Heald, E. P. Meinecke, Caroline Rumbold, and Mr. W. H. Long, of the Bureau of Plant Industry, for many helpful criticisms of the manuscript. The investigations were conducted at the Forest-Products Laboratory, Madison, Wis., maintained by the Forest Service of the United States Department of Agriculture in cooperation with the University of Wisconsin.

Note.—This bulletin gives the results of a series of investigations conducted at the Forest-Products Laboratory, Madison, Wis., as to the preservative value of various oils and salts and their toxic effect on wood-destroying fungi.

economic considerations as far as the preservatives used are concerned. These preservatives have in a general way proved to be fairly good, but recently further efforts have been made to supplement them, or perhaps to substitute for them under certain conditions other substances which may be more applicable to certain requirements.

In addition to the toxicity of a preservative toward wood-destroying organisms, its value to the trade will depend largely upon its varied physical and chemical properties, as well as upon certain economic considerations involved. The present publication, however, deals only with the toxic properties. Considerable literature on the toxic effect upon plant and animal life of various chemical substances, both inorganic and organic, has accumulated, but relatively little work has been done with wood-destroying fungi, and any attempt to draw analogies would be misleading.

Even among fungi the toxic concentration of a given preservative will vary, depending upon the organism, the concentration of the preservative, and the growth conditions, such as the composition of media and the temperature. In order to call attention to the fundamental character of certain of these variations and to illustrate the points involved, a brief survey of some of the work of other investigators is here presented before the results of our own work are discussed. No attempt has been made to review all the literature on this extensive topic, and only a few references which serve to illustrate the points the writers desire to emphasize are included.

HISTORICAL.

STIMULATION BY TOXIC SUBSTANCES.

Many investigators have established the fact that certain substances that are poisonous in higher concentration exert only a stimulating effect in extreme dilution. For many years the fluorin compounds have been known to have this stimulating effect upon fermentation. Ono (22)[1] and Raulin (24) have found similar favorable influences exerted by lithium nitrate and sodium fluorid upon algæ and by mercuric chlorid and copper sulphate upon fungi. Fred (9), in his studies on nitrogen fixation, denitrification, ammonification, and putrefactive processes in soils, due to certain bacteria and yeasts, concludes that the yield is in proportion to the toxic stimuli. Likewise, Clark (3, p. 400), in his work on the toxic effect of many acids and salts upon fungi, found that many deleterious agents which at certain concentrations retard germination or early growth afterwards cause a great acceleration of mycelial development.

[1] Figures in parentheses refer to the bibliography at the end of this bulletin.

VARIATION IN TOXICITY OF CHEMICAL SUBSTANCES TO DIFFERENT FORMS OF PLANT LIFE.

A review of the literature on the action of various toxic agents shows that the different forms of plant and animal life often behave very differently toward the same chemical substance. However, on account of the complexity of the digestive and absorptive processes in the higher animals, particularly man, a direct comparison of these forms with plant life is of little value, although the economic consideration of safety in the handling of substances in commercial use is of great importance.

A few general statements to indicate in a concrete form the differences in behavior between the larger plant groups, as well as individual species, will illustrate the point which it is desired to make.

It is unfortunate that the work of different authors can not, in many instances, be directly compared, on account of differences in the method employed. However, much of value can be deduced from the few available examples.

In his valuable work, Clark (3) calls clearly to the attention the variations among different species of molds. Certain toxic agents are shown to present great differences in this respect and others only slight ones. Even the stage of development of a single organism is of great importance, the conidia of the five species used proving more sensitive than the mycelium, so that the inhibition point for spore germination can not safely be considered as the toxic point for the development of mycelium.

Other species of fungi, however, may behave differently from the ones Clark worked with, for Rumbold (25, p. 431) has recently shown that the ascospores and conidia of the blue-stain fungus (*Ceratostomella* sp.) are more resistant than the mycelium to sodium hydroxid and sodium carbonate.

Another interesting phase of the question has been studied by Pulst (23). This investigator shows that the common green mold (*Penicillium glaucum*) has the power of gradually increasing its resistance to toxic agents. He claims that the individual itself without change of generation, but after a somewhat longer period of time, works up its resistance to copper sulphate to a high degree. He also shows by experiment that spores sown from generation to generation on progressively increasing concentrations of this salt likewise attain greatly increased resistance. Similarly, this newly developed resistance is evidenced by an increased rate of growth. For instance, when spores produced on a 3.2 per cent solution of copper sulphate are transferred to new media of like concentration, the mold will fruit again in about 10 days, while spores obtained from a culture containing no toxic substance and transferred in exactly the same manner require more than three months to reach the same stage of development.

Seed plants.—A great amount of work has been done to ascertain the effect of various toxic substances on the roots of higher plants. A discussion of this work, however, is not essential to the present paper beyond showing that a considerable difference exists between the behavior of this group of plants as compared with the lower forms.

In the comparison by Harvey (11) of his own work on an alga (*Chlamydomonas multifilis*) with that of True and Hunkel (30) on a flowering plant (*Lupinus albus*), both investigators using the ortho, meta, and para compounds of dihydric phenol, cresol, and phthalic acid, the alga was found to withstand a concentration three to eight times as high as the flowering plant.

Another striking illustration of this varied response to the same toxic solution is recorded by Heald (12, p. 130), who found a fungus vigorously growing on pea roots which had been killed by hydrochloric acid. The average death point for five species of molds studied by Clark (3, p. 306) was $\frac{n}{3.3}$ HCl (1.1 per cent), while the three species of flowering plants investigated by Heald (12, p. 132) succumbed at $\frac{n}{1600}$ HCl or less.

When copper sulphate was used, Kahlenberg and True (14) found that 0.00062 per cent was sufficient to kill the roots of *Lupinus albus*.

After many experiments, Clark (3, p. 396) concludes that in the case of mineral acids a concentration of 2 to 400 times the strength fatal to the higher plants is required to inhibit the germination of mold spores under favorable conditions.

Bacteria.—Although no direct comparison of bactericidal and fungicidal action is available, the experiments being usually performed under somewhat different cultural conditions, the work of McClintic (17) on zinc chlorid indicates a high resistance of certain bacterial organisms. This investigator found that a 5 per cent solution of zinc chlorid applied for one hour was not sufficient to kill *Bacillus communis*, while a 25 per cent solution required 10 minutes to cause death. At this latter concentration 30 minutes was required to kill another bacterial organism (*Staphylococcus pyogenes aureus*).

Spores of bacteria are well known to be very resistant to various agents. In the case of *Bacillus subtilis*, they are reported to have survived a 50 per cent solution of zinc chlorid for 40 days.

These figures are of interest when one recalls that a 3 to 6 per cent solution of this salt is the usual concentration employed in the preservation of wood.

Yeasts.—Yeasts seem to behave toward many salts and acids very differently from seed plants and fungi. Bokorny (1) has re-

cently reported the effect of about 50 different salts and acids upon yeasts, as compared with other organisms, and has found them generally to be more resistant than algæ or flowering plants. Silver nitrate, which is very deadly to many molds, bacteria, and algæ (the bacterium *Staphylococcus pyogenes* requiring only 0.0002 per cent to check growth; the algæ, Spirogyra and Cladophora, only 0.0001 per cent), will not kill yeast until the concentration reaches 0.001 per cent. Similarly, mercuric chlorid is toxic to Spirogyra in a 0.000001 per cent solution, but a 0.01 per cent solution is required to kill beer yeast.

Molds.—The common molds, such as Penicillium, Aspergillus, Sterigmatocystis, and others, taken as a whole, are highly resistant to toxic agents as compared with the true wood-destroying fungi.

Whereas much experimental work has been done on the former, comparatively little has been carried out on the latter group.

The so-called *Penicillium glaucum* Link., which in the light of recent work has been shown to consist of a group of several distinct species of Penicillium, to which the composite name was indiscriminately applied, is one of the most resistant molds recorded. Pulst (23), Clark (3), and Guéguen (10) all agree that from 16 to 21 per cent of copper sulphate is required to stop its growth, and Pulst claims that it will even germinate and fruit in a 33 per cent solution of this salt or a 38 per cent solution of zinc sulphate if allowed to develop a sufficiently long time, i. e., from three to five months.

Clark (3) has tested the effect of some 28 salts and acids upon four or five of the common molds, the tests being made in hanging drop cultures of beet infusion. His table of toxicities indicates that such salts as mercuric chlorid, potassium bichromate, silver nitrate, and potassium chromate are approximately 400 times as effective against these organisms as copper sulphate, sulphuric acid, hydrochloric acid, and zinc sulphate, the comparison being based on molecular solutions.

EFFECT OF COMPOSITION OF MEDIUM ON TOXICITY.

The toxicity of a substance may vary for the same organism when culture media of different compositions are employed. This is due, in large part, to the chemical or physical affinity of some substances for certain constituents of the media, or possibly to some change in the permeability of the plant protoplasm. The well-known reaction of some copper salts with sugars and of mercuric chlorid with albuminous compounds, or the effect of adsorption will serve to illustrate the point.

The most careful work on toxicity has been conducted, using pure distilled water as a medium. However, the use of this method with fungi is practically limited to the germination of spores; nutrient

substances must be added if further growth is desired, and the addition of each nutrient substance introduces a new factor of error.

Unlike bacteria, which can be grown well in synthetic liquid media of known composition, wood-destroying fungi prefer a more complex and solid medium for their satisfactory development. This latter, as a rule, consists of a mixture of meat broth and sugars solidified by agar-agar or gelatin.

Various investigators have used different types of media and different methods, and this accounts in large part for the variability in results. Some, as Clark (3), have used simple plant decoctions, others bouillon, and still others a nutrient agar or gelatin modified in various ways as to available carbon and nitrogen.

Le Renard (16), in his work on *Penicillium crustaceum*, shows that toxicity is closely associated with the composition of the medium and in the same medium varies somewhat with its concentration.

Likewise the presence or absence of certain constituents may determine the temperature which an organism will endure on different media, for Thiele (27) has shown that the maximum temperature for the growth of *Penicillium glaucum* on grape sugar is 31° C.; on salts of formic acid, 35° C.; and on glycerin, 36° C.

Hoffmann (13) states that in the case of *Merulius lachrymans* a slight growth takes place even at 30° C. on certain liquid media, while on solid media (5 per cent agar-agar) the fungus was killed at that temperature. He likewise thinks that as a fungus becomes accustomed to a certain culture medium in its development it gradually overcomes certain unfavorable conditions.

So far as the writers are aware at the present time, the media most satisfactory for the growth of wood-destroying fungi are not free from the objection of being complex, variable, and more or less unknown in their chemical composition; however, certain synthetic media are being developed in the course of the work which show promise of being satisfactory. In an effort, however, to secure results comparable as far as possible with those of certain European investigators, such as Malenković and various workers at Munich, and also Rumbold in this country, the malt-extract agar medium used by these workers has been adopted. This medium will be described later.

EFFECT OF ADSORPTION ON TOXICITY.

The apparent diluting effect which inert, practically insoluble matter exerts on toxic substances has been often observed. For instance, the injurious effect of poisons is not so noticeable when seedling roots are placed in sand and watered with toxic solutions of definite concentration as when grown directly in such solutions. This phenomenon of the removal from solution of a part of the toxic substance by nearly insoluble material, such as glass, quartz, pottery,

hemp and cotton fibers, and starch grains, comes under the general term "adsorption." It is often explained as a direct physical affinity of the toxic chemical for the inert substance; that is, a condensation of the substance on the surface or in the interstices of the insoluble matter, or the formation of a solid solution of the two, but chemists and physicists are not at all in agreement in regard to these explanations.

Among others, True and Gies (29) and True and Oglevee (31) worked upon this problem, using seedlings of *Lupinus albus* and a number of inorganic and organic compounds. As adsorbing agents such substances as sand, glass, filter paper, and paraffin were applied. With copper sulphate they found that at least twice the usual toxic concentration could be endured by the Lupinus roots when a sufficient quantity of the insoluble matter was added to the hypertoxic solution. In summarizing their work they remark:

> It appears in general that the presence of a considerable body of certain insoluble substances in solutions of strongly toxic compounds both organic and inorganic in their nature, be they electrolytes or not, tends to decrease the toxic activity of the solutions in question. On the whole this ameliorating action is more clearly marked in case the poisonous solutions concerned are dilute solutions of strong poisons than when relatively concentrated solutions of weaker poisons are concerned.

Fitch (8) conducted a series of experiments with sulphuric acid and copper sulphate, using pottery, glass, sand, and filter paper as the adsorbing agents and two common molds (*Aspergillus niger* and *Penicillium glaucum*) as the test organisms. She established for fungi the same phenomena of dilution that a number of other workers had found to hold for flowering plants.

The diversity of results secured when toxic substances are tested on various media, particularly such as contain starch grains and similar materials in suspension, no doubt is explained, in part at least, on the basis of adsorption.

RELATION OF TEMPERATURE TO FUNGOUS GROWTH AND TOXICITY.

It is well known that temperature exerts a vital influence on the growth and development of fungi. Not alone is the temperature range which permits the growth of the organisms highly variable, but also the optimum temperature in many cases varies for the different species. Thus, for nine species of wood-destroying fungi studied, Falck (5, 6) indicated a growth range lying between 3° and 44° C., with the corresponding optima between 18° and 35° C. For *Merulius domesticus* (= *M. lachrymans* in part) this optimum falls between 18° and 22° C.[1]; for *Coniophora cerebella*, 22° to 26° C.; for *Polyporus vaporarius spumarius*, 26° C.; for *Lenzites abietina*, 29.5° C.; for

[1] Hoffmann (13) states that under certain conditions of culture this optimum may be raised so as to fall between 18° and 26° C.

Lenzites sepiaria, 28° to 32° C.; and for *Lenzites thermophila*, 35° C. Below these temperatures growth becomes greatly lessened as the minimum is approached, while a rise of 4 to 8 degrees above the optimum often causes a total inhibition of growth or even death in the case of very sensitive species.

Different stages of the same fungus may also offer a different resistance to temperature changes, this being much less under moist than under dry conditions. For instance, Falck (7, p. 339) found that fresh fruit bodies of *Merulius domesticus* were killed in 30 minutes at 40° to 42° C., and in 15 minutes at 46° C., while from 12 to 16 hours were required to kill dry spores at 42°.

As compared with this fungus, the same author shows that agar cultures of *Lenzites sepiaria* can survive more than three hours at 60° C.

The resistance of a fungus to toxic substances is greatest under temperature conditions most favorable to its development. After conducting a series of tests on several molds to determine the germinative capacity of the spores in varying concentrations of nitric and sulphuric acids and copper sulphate at different temperatures, either directly in the solutions or after removal to nutrient media following immersion for 24 hours, Brooks (2) states that "in most cases the deleterious action increased very rapidly with rise in temperature," but that "in all instances the injurious effects were least at the optimum for the fungus."

RELATION OF LIGHT TO FUNGOUS GROWTH.

Light also exerts an appreciable effect on the development of wood-destroying fungi. This is evidenced in two ways: (1) By its influence on the growth of the mycelium, and (2) by the rôle it plays in the production of normal fruiting bodies. In most instances at least, partial illumination is essential to normal fruiting. The effect on the rate of growth of the mycelium, however, is less marked, but still quite appreciable. Of seven species of wood-destroying fungi studied, Hoffmann (13) reports that growth in the dark was from 4.1 to 17.8 per cent (average 9.9 per cent) better than in sunlight. In carrying his experiments still further and examining the effect of the red and blue ends of the spectrum, respectively, he found that the former gave 2.6 per cent better growth in the case of *Paxillus acheruntius* and 59.3 per cent in the case of *Polyporus vaporarius* (average for nine fungi 14.6 per cent).

WHAT DETERMINES TOXICITY?

An adequate discussion of the subject of what determines toxicity would lead us into one of the most difficult fields of biological chemistry and physiology, hence, for the purposes of this publication, the writers omit reference to a great mass of literature covering the

more involved aspects of the question and merely bring forward a few of the points which serve to illustrate certain phases.

In the previous discussion it has been seen that the degree of toxicity manifested is relative and closely associated with the environmental conditions and the particular physiological constitution of the individual organisms under consideration, as well as with the concentration of the different toxic substances employed and the chemical and physical relations which these bear to the media upon which the organisms are grown. Why certain concentrations of substances are toxic to one plant and not to another, or why the same species varies in its tolerance to a certain toxic agent, is more or less obscure. According to Heald (12, p. 126) it may be a case of "adaptation and adjustment," and this is at least suggested by the work of Pulst (23) in increasing the resistance of *Penicillium glaucum* to copper sulphate. In support of his view Heald further states:

> Those substances which are poisonous to plants are generally such substances as are not accessible to plants in their normal habitats, at least to any extent, while those substances which are generally present in the soil have no injurious effect, or at least not in the same degree of concentration at which we find them in the soil.

However, for the purposes of the present paper the question of how the toxic substances exert their effect is not so near to the point as is the question of what particular components of the substances are the effective ones. On the basis of the separation of compounds into their constituent ions (elements or radicals) when brought into solution, many efforts have been made by comparison of different substances which have certain ions present in varying proportions to determine the most active part of the molecule. As many substances, particularly the more complex, do not become completely dissociated in solution, experimental work largely draws its inferences from the simpler compounds, mainly the inorganic.

As a result of work on such ionized molecular solutions, investigators quite generally agree that in case of the salts of heavy metals, like copper and mercury, it is the metallic ion that is largely effective. In the case of strong acids, such as hydrochloric and sulphuric, the hydrogen ion is said to be the principal toxic element. The work of Kahlenberg and True (14) proves the great activity of hydrogen and shows that in mixtures of such acids the toxicity is proportional to the number of free hydrogen ions present.

In 1900 True (28) published an account of the investigation of 20 acids, both inorganic and organic, together with their sodium salts, in an effort to extend our knowledge of the effective toxic elements, the toxicity tests being conducted on the roots of *Lupinus albus*. With the simple inorganic acids, which readily dissociate in solution, he corroborated earlier views that the H ion gives the greater part of the toxicity to the solution, the corresponding sodium salts of the

acids being only slightly toxic. With the organic acids, in which ionic dissociation is usually less complete, he also found that the relative importance of the H ions in general varied with the percentage of dissociation. If the dissociation was relatively slight, the nonionized molecule itself exerted the predominating influence. In general, the anions of organic acids were found to possess relatively slight toxic properties, oftentimes so slight as to be almost negligible, and, since both the sodium ions and the anions were usually but weakly toxic, it followed, as a rule, that sodium salts showed but 0.5 to 3 per cent of the toxic value of the corresponding acids. Carboxyl hydrogen proved much more toxic than hydroxyl hydrogen. Since in the phenols this latter form of combination occurs, and since these substances do not ionize, the toxicity here must be referred entirely to the undissociated molecule.

In order to throw further light on the behavior of phenols and their derivatives True and Hunkel (30) extended their investigations on *Lupinus albus* to this group. The results bear out their earlier conclusions that electrolytic dissociation of phenylic bodies plays but a very subordinate rôle in determining their toxicity. However, in a few instances, such as with picric and salicylic acids, the cresols, and the mononitrophenols, electrolytic dissociation is said to exert a pronounced influence. Some phenols also, like pyrocatechol and hydroquinone, which are comparatively unstable, may quickly change to constituents even more fatal than H ions. Certain radicals seemed also to have specific properties when introduced into the molecule. For instance, the number of hydroxyl groups appeared to have little influence, while the introduction of the methyl group into the benzene nucleus increased the toxicity to a considerable but variable degree, as shown by the cresols and less plainly by orcinol; however, replacing the H of a hydroxyl group by a CH_3 group had little effect. The introduction of the isopropyl group into the cresols further increased their toxicity. The presence of one or more nitro groups likewise increased toxicity to a great degree, but the number of these groups seemed to make little difference.

Similarly, in the case of certain organic compounds (cf. 7, pp. 351–352), Ehrlich and Bechhold have shown that the introduction of halogen and alkyl groups into the benzol ring increases the toxicity of phenols to diphtheria bacteria, two molecules of pentabromphenol being about equal to 40 molecules of trichlorphenol and 100 molecules of phenol. On the other hand, the introduction of the carboxyl group was said to lessen toxicity.

Likewise, Falck (7, pp. 355, 357) states that nitrophenols and dinitrophenols are considerably more toxic than phenol and more so when the nitro groups are in the ortho position than when in the meta or para position. The most effective of 19 nitrophenols which he tested

in Petri dishes on agar against the fungus *Coniophora cerebella* were the sodium or potassium salts of dinitrophenol ($C_6H_3 \cdot (NO_2)_2[2.4] ONa$) and dinitro-orthocresol ($C_6H_2 \cdot CH_3\, [2] \cdot (NO_2)_2ONa$).

Generalizations, however, are not always applicable by analogy and may serve only for certain limited groups. In his work on numerous fluorin salts Netzsch (21) found that the fluorin ion was the most active, the relative toxicity of the simpler and consequently more readily dissociated salts, at least, being in direct proportion to the amount of fluorin in the molecule. When the acid (HF) itself, however, was under consideration it was found to be even more toxic than its simple metallic salts, indicating the great activity of free hydrogen.

TESTS OF THE TOXICITY OF WOOD PRESERVATIVES.

It is only within the past decade that laboratory tests to determine the relative toxicity of substances adapted particularly to wood preservation have been undertaken. These lack the refinement of earlier work, as it was not the intention to enter into the question as to why and how a substance was toxic, but merely to determine how much of a given poisonous substance was necessary to inhibit the growth of fungi, particularly the wood-rotting forms. The result is that different investigators have used different methods, different culture media, different organisms, temperature conditions which were often not the optimum for the fungi concerned, and ofttimes also impure chemicals and composite oils, such as creosotes, that no other investigator is able to duplicate except from the same sample.

The problem has been attacked in two ways: (1) By mixing the preservative under consideration with various types of culture solutions, usually solidified by the addition of agar-agar or gelatin, and inoculating with the organisms desired; and (2) by injecting the preservative into wood and exposing the blocks thus treated to the action of wood-destroying fungi.

Tests of this sort were first suggested by Malenković (18) in 1904. The results of his work were first published in an Austrian military journal and later (19) amplified and printed in book form. He lays no claim to refinement of work, so it is difficult to correlate his results with later ones, except in a general way. The larger part of his experiments were carried out by injecting the preservative into wood, but a few beaker tests were made according to the following plan:

Five glass beakers were filled with 100 c. c. of 10 per cent gelatin or 2 per cent agar media, and to each was added a certain amount of the antiseptic, such as 0.5, 1, 1.5, and 2 grams. The media were then melted, thoroughly stirred, and allowed to cool. Then, without any previous sterilization, a trace of some mold (unknown to the experimenter) was transferred to the surface of the media, and the cultures were set away in a dark, damp place. After 14 days observations were made to determine whether the surface had become moldy. The concentration that prevented mold growth was recorded as the toxic point for the preservative in question.

As has been shown in the preceding discussion, tests that are conducted under any other than pure-culture conditions are not directly comparable with each other, for the different organisms react in an entirely different way to the same chemical substance. Moreover, the use of molds which at most produce but slight effect upon wood gives no more than the roughest approximation as to how wood-destroying organisms would behave under similar conditions.

In 1910 Netzsch (21) conducted an exhaustive series of experiments on the toxicity of fluorin compounds. As these compounds have only recently entered into the field of wood preservation, and as many of them have proved to be toxic agents of high efficiency, his work is of great technical value. He carried out the work much as Malenković and other investigators have done, both by mixing the substances in gelatin culture media and injecting them into wood, but his tests on culture media were carried out under sterile conditions in flasks, tests tubes, or Petri dishes, so that many of the objections to the work of Malenković were eliminated. Into the gelatin media were introduced varying proportions of equimolecular solutions of the fluorin compounds. The culture vessels were then inoculated, using both *Coniophora cerebella* (a true wood destroyer) and the green mold, *Penicillium glaucum*, the former being maintained for about four weeks in an incubator at 20° to 21° C. His results, showing the point of inhibition of growth, are presented on the basis of one gram molecule of the preservative to the number of liters of culture media necessary to secure the proper concentration. In the present paper this ratio has been changed to the percentage basis (weight of preservative in volume of media), in order to compare his results with those of other investigators.

About this same time Seidenschnur (26), head chemist of the wood-preservation laboratory of the Rütgerswerke-Aktiengesellschaft, at Berlin (Charlottenburg), presented the results of a few tests upon the comparative toxicity of zinc chlorid and tar oils. His experiments were conducted in test tubes containing gelatin media mixed with varying proportions of the antiseptics. After the mixture was prepared, the tubes were sterilized for one-half hour at 80° C.[1] The tubes were then slanted and inoculated with *Penicillium glaucum*. The toxic point was not determined, but the relative efficiency of the two substances was compared in parallel cultures.

During 1911, J. M. Weiss (33, 34), chemist in the technical laboratories of the Barrett Manufacturing Co., New York City, published the results of a number of experiments to test the relative antiseptic value of creosotes and other oils. The substances were mixed in agar media. The organisms used consisted of a bacterium (*Bacillus subtilis*), a yeast (*Saccharomyces glutinis*), and a species of Penicillium.

[1] This treatment, however, is usually considered insufficient to insure sterility.

An effort was made to handle them in pure culture under sterile conditions. The selection, however, of test organisms which play at most but a slight rôle in the decay of timber is not to be recommended. As many factors of error as possible should be eliminated from such tests, for there are certain to be many remaining after all precautions are taken.

During the same year Rumbold (25) carried out a series of tests with different wood preservatives, using agar media in Petri dishes as well as toasted bread soaked in the antiseptics. In the case of the agar cultures, the media and preservative were mixed before sterilization. This procedure is known to lead to very erroneous results with certain substances, such as zinc chlorid and copper sulphate. In all cases the preservative and media should be sterilized separately and heated no higher than is necessary during the mixing, in order to avoid as far as possible any chemical combination which tends to occur. The higher concentrations of the salts mentioned above cause a liquefaction of agar or gelatin media when sterilized together. One test conducted in our laboratory showed that zinc chlorid at 0.6 per cent concentration when sterilized after mixing allowed even more growth of *Fomes annosus* than 0.2 per cent when the two components were not sterilized together. Concentrations of the sterilized mixture below about 0.4 per cent appeared to be stimulative, giving a white, fluffy growth, which was more luxuriant than in the creamy check cultures and which grew up over the under side of the covers of the Petri dishes.

The use of bread for culture media likewise is objectionable, for the starch therein contained possibly acts as a diluting agent, as already indicated in the discussion of the phenomena of adsorption. For instance, in comparing Rumbold's tests of sodium carbonate on bread and on agar it is seen that considerably more of the preservative is required to check the growth of the organisms when the former medium is used.

In 1912, Falck (7), and Dean and Downs (4), published the results of work on various wood preservatives in agar media, using wood-rotting organisms.

The former covered a wide range of possible preservatives (some 60 or 70), including phenols and cresols and their derivatives, benzol derivatives, fluorin compounds, acids, alkalies, and inorganic metallic salts. The work appears to have been very carefully done and is an extremely valuable contribution to the subject. It is open to the objection, however, that the tests were of too short a duration.

Dean and Downs report only a few tests on tar oils in a bean-agar medium, using the cosmopolitan wood-rotting fungus *Polystictus versicolor*. These investigators introduced a method of preparing creosote emulsions with gum arabic, which was considered advanta-

geous,[1] particularly with heavy oils. They also attempted to improve upon the usual method of inoculating the surface of the culture with the mycelium of the test organism by cutting a small block out of the medium, placing the transferred mycelium in the aperture, and then covering this with the portion of medium which was originally removed. They claimed this would give a more accurate indication of whether the fungus was really growing on the treated medium or only on the fragment of medium which must necessarily accompany the mycelium when it was transferred. This appears, however, from work in our laboratory, to be a refinement of doubtful expediency, for it has often resulted that when fresh, actively growing mycelium is placed in intimate contact with the poison it will be directly killed, while if it has the opportunity to recover its vigor to a certain extent after the disturbance in its growth equilibrium, due to cutting and removal from the original culture, it may eventually withstand concentrations which would otherwise be fatal.

The more important results of these different investigators are presented in Table IV (pp. 31–34).

TESTS CONDUCTED AT THE FOREST-PRODUCTS LABORATORY.

SCOPE OF THE WORK.

The experimental work in wood preservation at the Forest-Products Laboratory includes a physical, chemical, and pathological examination of various substances which may have a possible value in the industry (32). Therefore, since toxicity is but one factor, conclusions regarding the service value of these substances should not be drawn without giving due consideration to other factors.[2] The pathological tests are made in Petri dishes, using agar media, or by injecting the preservatives into wood and exposing the wood to the action of wood-destroying organisms. Only the Petri-dish method is herein described. This method has the advantage of giving results from which at least tentative conclusions can be drawn in a relatively short time. Conversely, it is open to certain objections for which due allowance must be made in generalizations regarding the possible behavior of a preservative when placed under service conditions. However, in experimental work on the toxicity of different chemical substances it is often very necessary to secure indicatory results as soon as possible. In this way many substances may be eliminated which are not worthy of further trial. After a preservative has been shown to possess high toxic properties under

[1] From the purely physical side of preparing the preservatives so they can be more readily handled the gum-arabic emulsions have proved satisfactory to the writers, but the gum arabic apparently reduces the toxicity to such an extent as to forbid its use in comparative tests. This fact has been determined since this manuscript was prepared.

[2] See U. S. Dept. of Agriculture Bulletin 145, "Tests of wood preservatives."

Petri-dish conditions, tests on its properties when injected into wood should follow, under both laboratory and service conditions.

Recently, an attempt has been made by a European investigator (20) to correlate Petri-dish results directly with service values. First, the preservatives were grouped as nearly as possible according to their permanence in wood. Then, knowing the average length of life of the treated timbers, the amount of preservative necessary to inject to give this life, and the toxic point of the substances as indicated by Petri-dish tests, a curve was plotted using the first factor as the axis of ordinates and the ratio existing between the second two as the axis of abscissas. From this curve the investigator would predict the possible service value of any new preservative of like permanence in wood merely from the known Petri-dish ratio by locating the point at which its ordinate intersects the standard curve.

Such mathematical calculations are interesting, but must necessarily be very limited in their application, since such variables as the solubility and volatility of the preservatives, the nature of the timber treated, and the soil and weather conditions to which the treated wood is exposed must necessarily exert a great influence on the length of the life of the material.

At the Forest-Products Laboratory, 2,400 Petri-dish tests have been made to date on 54 different substances; however, not all are sufficiently complete to be reported. These include a few water-soluble salts, but in the main they comprise various oils and tars. These preservatives have been for the most part submitted by American and European cooperators interested in having the substances examined.

The tests were conducted using two wood-destroying organisms, *Fomes annosus* Fr. and *Fomes pinicola* (Sw.) Fr., which have a wide American and European distribution and are very important in the decay of wood, particularly coniferous timber. The former is undoubtedly the most serious fungus of coniferous mine timbers in the United States.

In general, the molds used by other investigators may be considered more resistant than the true wood-destroying fungi, but the writers have considered it advisable to use only wood-destroying forms, in order to eliminate any possibly erroneous inferences.

METHODS OF TESTING TOXICITY.

The method of conducting the tests was in principle the same as that used by other investigators, merely involving the mixing of the various preservatives in definite proportions with media nutrient to fungi. However, an attempt was made to refine the methods as far as possible, so as to eliminate certain sources of error to which attention has already been called.

A culture medium made according to the following formula was used:

Extract of 1 pound lean beef in distilled water	1,000 c.c.
Löfflund's malt extract	25 grams.
Agar-agar	20 grams.

(Carefully filtered, but reaction not adjusted; slightly acid.)

This is the formula largely used by German investigators. It is a good medium for the development of fungi, but, like all other media of organic and often unknown composition, offers the objection of possible chemical reaction with certain preservatives. However, such synthetic media as were experimented with proved very poor substrata for the development of the organisms.

The above medium after melting was measured [1] into 50-c. c. glass bottles with carefully ground glass stoppers, usually 17 c. c. to a bottle, using a standardized 17-c. c. pipette or a 25-c. c. graduate. One check was usually prepared for each series of concentrations and to this was added sufficient distilled water to make 20 c. c. The stoppers were then sealed in with a rubber-glycerin burette-cock grease and capped with a small piece of muslin. The bottles were clamped in specially constructed frames (Pl. I, fig. 1) and given a sterilization of 25, 20, and 20 minutes, respectively, at 100° C. on successive days.

The handling of the preservatives involved slight modifications for individual cases, but in all instances concentrations are based on the actual weight of the preservatives in grams in 20 c. c. agar-preservative mixture.

With inorganic salts soluble in water solutions were prepared varying from 3 to 10 per cent concentration (grams in 100-c. c. solution), and these were used by measuring into 50-c. c. bottles, similar to those used for agar, the desired amount of solution, using either a 10-c. c. or a 25-c. c. standardized burette graduated in twentieths or tenths of a cubic centimeter, respectively. To each bottle was then added sufficient distilled water to make 3 c. c. In all cases concentrations were based on the weight of dry salt present.

All other preservatives were weighed into the 50-c. c. bottles on an analytical balance, and enough distilled water was added to make 3 c. c. In the case of a few viscous oils, namely, coal-tar creosote, coal-tar creosote Fraction V, wood tar, and wood creosote, which do not readily emulsify with water, 5 to 33⅓ per cent stock emulsions [2] were prepared, using equal amounts of gum arabic and preservative and diluting with distilled water to the desired concentration. These emulsions were then used in place of the crude preservatives.

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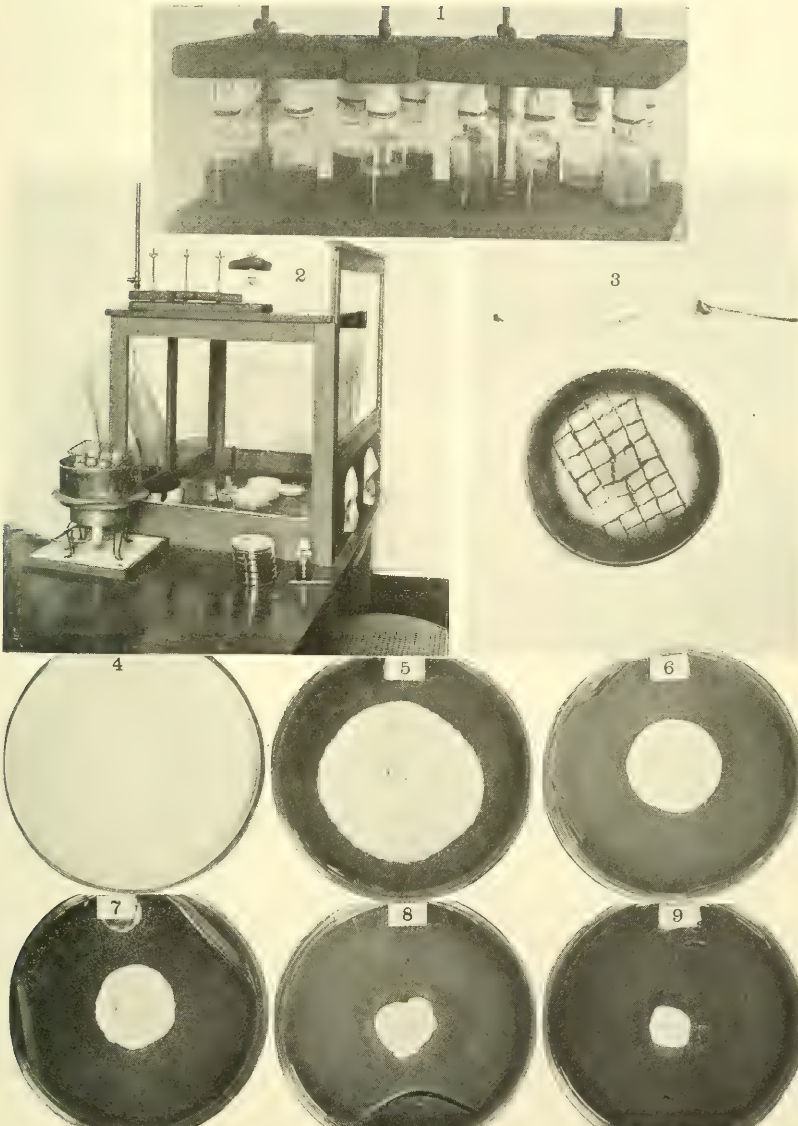
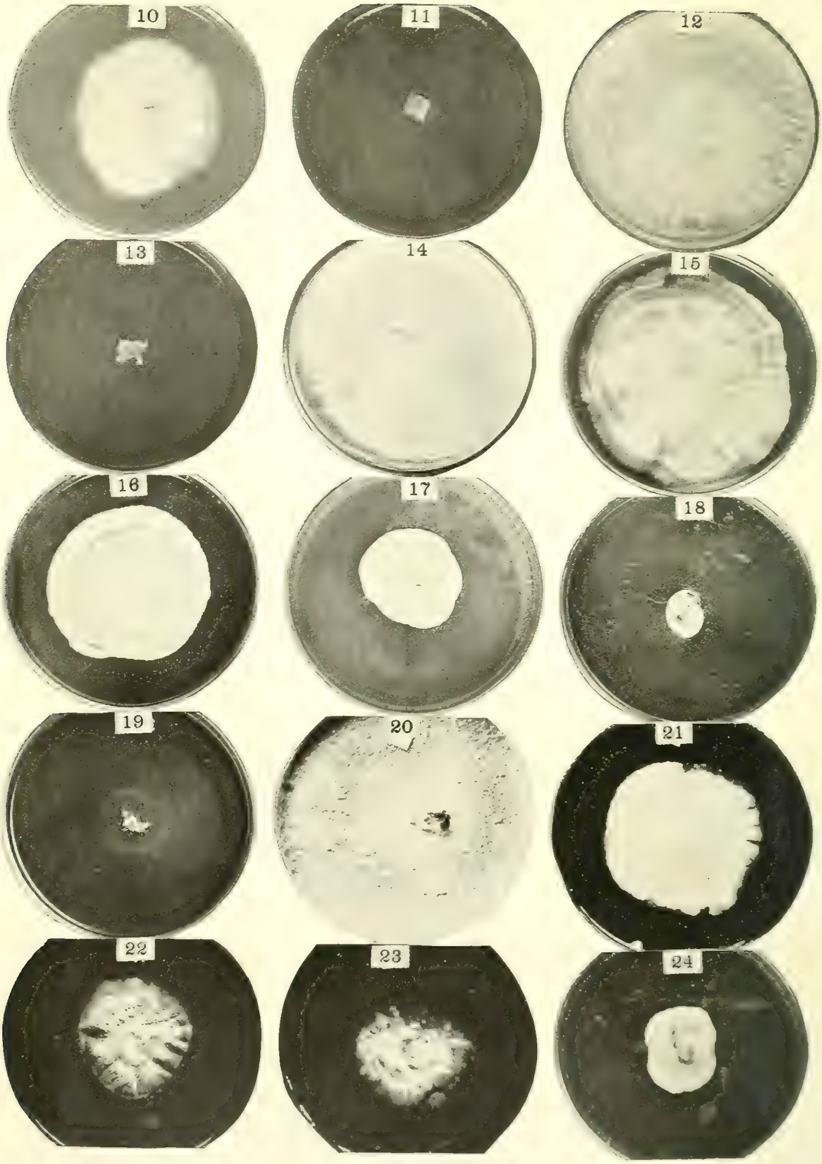
[1] In all measurements of agar one-half c. c. excess was allowed to cover the amount adhering to the glass containers.

[2] This method usually produced a quite permanent emulsion.



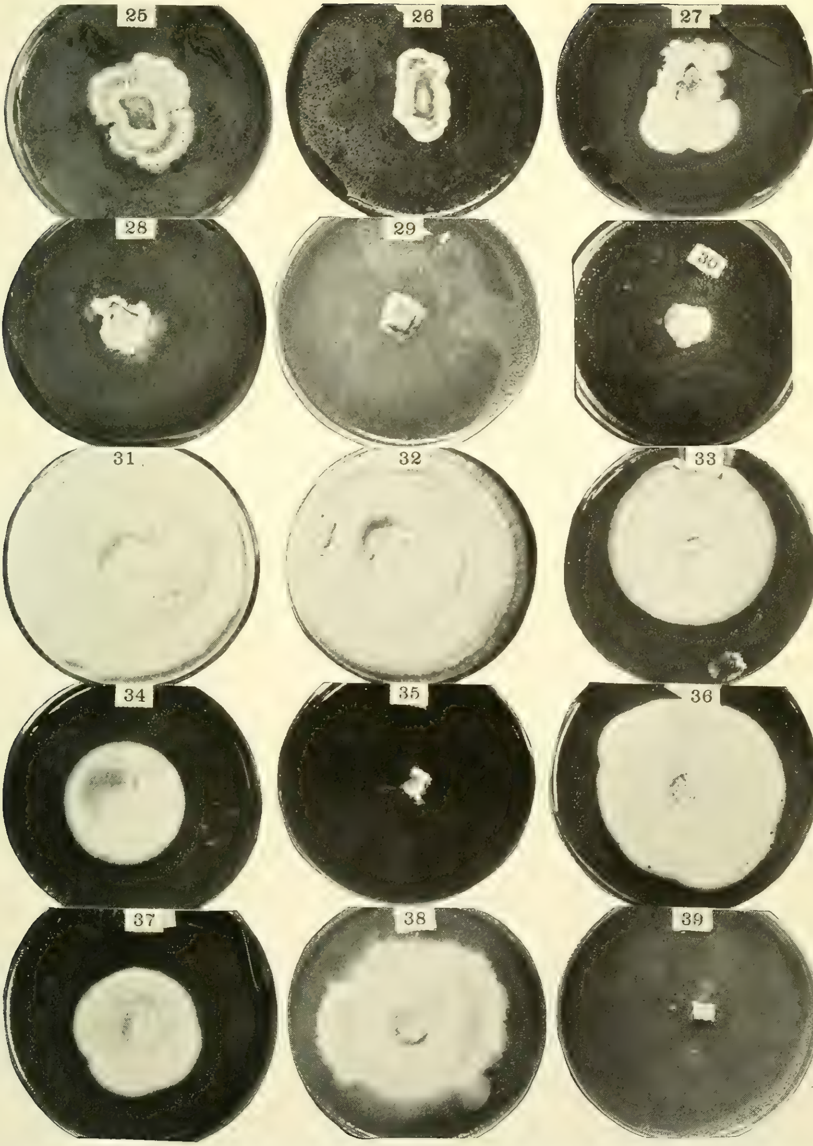
TOXICITY STUDIES: APPARATUS AND PETRI-DISH CULTURES.

FIG. 1.—Frame for agar and preservative bottles during sterilization. FIG. 2.—Inoculation case, showing water bath on hot plate and other apparatus used. FIG. 3.—Petri-dish culture of *Fomes annosus* cut into squares ready for transferring to the test plates; platinum needle with flattened tip used in the operation. FIGS. 4 to 9.—Petri-dish cultures of *Fomes pinicola* on different concentrations of coal-tar creosote, grade C, after 5 weeks: 4, Check; 5, on 0.075 per cent; 6, on 0.1 per cent; 7, on 0.125 per cent; 8, on 0.15 per cent; 9, on 0.175 per cent.



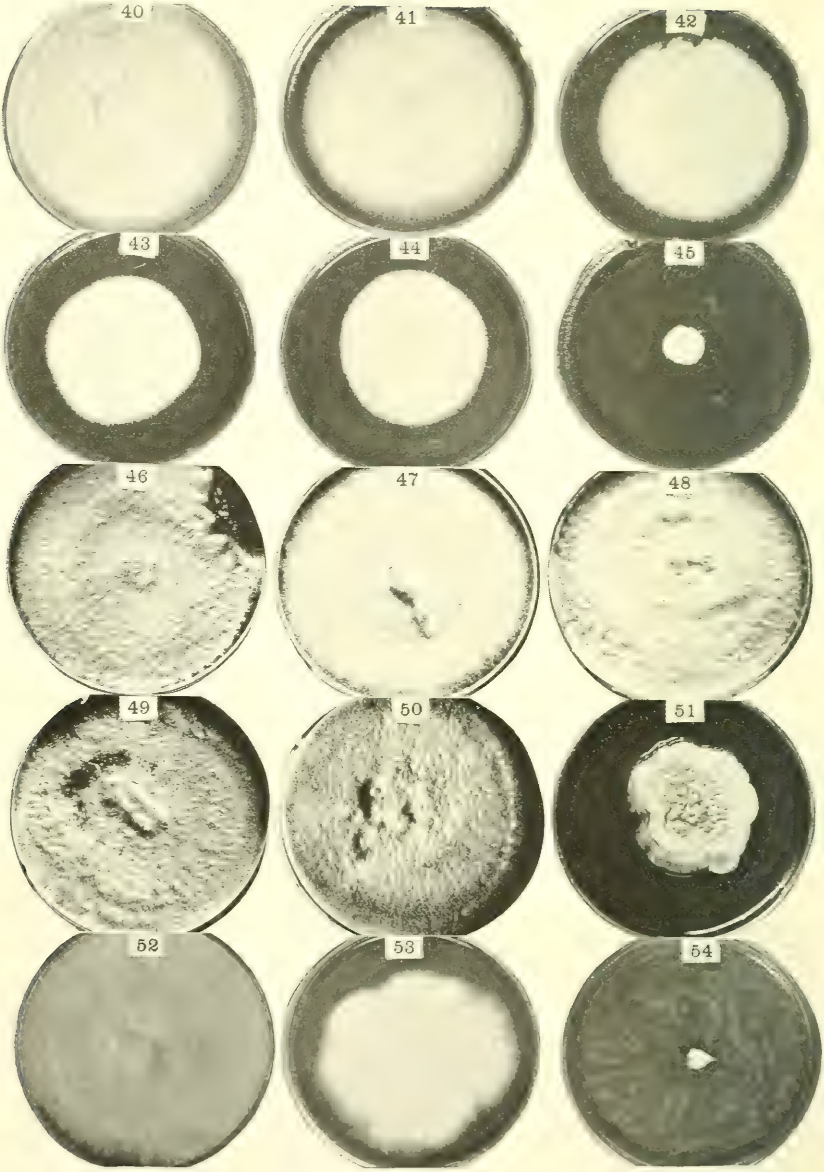
TOXICITY STUDIES: PETRI-DISH CULTURES OF FOMES ANNOSUS AND FOMES PINICOLA.—I.

FIGS. 10 and 11.—*F. annosus* on different concentrations of coal-tar creosote, Fraction I, after 5 weeks: 10, on 0.275 per cent; 11, on 0.3 per cent. FIGS. 12 and 13.—*F. pinicola* on different concentrations of coal-tar creosote, Fraction II, after 5½ weeks: 12, On 0.125 per cent; 13, on 0.15 per cent. FIGS. 14 to 19.—*F. pinicola* on different concentrations of coal tar creosote, Fraction IV, after 9 weeks: 14, Check; 15, on 0.025 per cent; 16, on 0.05 per cent; 17, on 0.075 per cent; 18, on 0.1 per cent; 19, on 0.125 per cent. FIGS. 20 to 23.—*F. annosus* on different concentrations of coal-tar creosote, Fraction V, after 7 weeks: 20, Check; 21, on 0.1 per cent; 22, on 0.5 per cent; 23, on 1 per cent. FIG. 24.—*F. pinicola* on 1 per cent concentration of coal-tar creosote, Fraction V, after 6 weeks.



TOXICITY STUDIES: PETRI-DISH CULTURES OF FOMES ANNOSUS AND FOMES PINICOLA.—II.

FIGS. 25 and 26.—*F. pinicola* on different concentrations of United Gas Improvement Co. 1.07 oil, No. 1101, after about 5 weeks: 25, On 20 per cent; 26, on 40 per cent. FIGS. 27 and 28.—*F. annosus* on different concentrations of water-gas tar distillate (sp. gr. 0.995 at 60° C.), after 6 weeks: 27, On 0.2 per cent; 28, on 0.3 per cent. FIG. 29.—*F. annosus* on 2.2 per cent concentration of S. P. F. carbolineum after about 6 weeks. FIG. 30.—*F. annosus* on 0.15 per cent concentration of coal-tar creosote, Fraction III, after 6 weeks. FIGS. 31 to 35.—*F. pinicola* on different concentrations of wood creosote (Douglas fir) after about 2½ weeks: 31, Check; 32, on 0.05 per cent; 33, on 0.1 per cent; 34, on 0.125 per cent; 35, on 0.15 per cent. FIGS. 36 and 37.—*F. annosus* on different concentrations of wood creosote (Douglas fir) after about 4 weeks: 36, On 0.2 per cent; 37, on 0.4 per cent. FIGS. 38 and 39.—*F. annosus* on different concentrations of cresol calcium after about 6 weeks: 38, On 0.14 per cent; 39, on 0.28 per cent.



TOXICITY STUDIES: PETRI-DISH CULTURES OF FOMES ANNOSUS AND FOMES PINICOLA.—III.

FIGS. 40 to 45.—*F. pinicola* on different concentrations of wood tar (hardwood) after 2 weeks: 40, Check; 41, on 0.2 per cent; 42, on 0.3 per cent; 43, on 0.4 per cent; 44, on 0.5 per cent; 45, on 0.6 per cent. FIGS. 46 to 48.—*F. annosus* on different concentrations of wood tar (hardwood) after about 3 weeks: 46, On 0.1 per cent; 47, on 0.5 per cent; 48, check. FIGS. 49 to 51.—*F. annosus* on different concentrations of copperized oil: 49, On 0.5 per cent after about 3 weeks: 50, on 1.75 per cent after about 3 weeks; 51, on 36 per cent after about $5\frac{1}{2}$ weeks. FIG. 52.—*F. pinicola* on 50 per cent concentration of None-Such Special after about $3\frac{1}{2}$ weeks. FIGS. 53 and 54.—*F. pinicola* on different concentrations of zinc chlorid (commercial) after 4 weeks: 53, On 0.7 per cent; 54, on 0.75 per cent.

In a few instances where the preservatives were low in toxic properties more than the specified 3 c. c. was necessary in order to secure the higher concentrations, and in these cases it became necessary to take into consideration the excess of preservative, and, considering it roughly as having the specific gravity of water, to reduce the agar by just this amount, in order that the combined volume might not exceed 20 c. c.

The concentrations to be used in the first series[1] of experiments on a given preservative were governed largely by the judgment of the investigator. The results thus obtained usually determined between what limits it was necessary to continue the work. The experiments were then carried on between these points, usually to within an accuracy of about 10 per cent for the actual and total inhibition point for each preservative. Thus, if growth stopped at 0.5 per cent or below, the tests were carried to the nearest 0.05 per cent; if between 0.5 and 1 per cent they were carried to the nearest 0.1 per cent, and so on up to the highest concentrations employed, usually 40 per cent, which would thus be tested to the nearest 4 per cent. This 40 per cent concentration is equivalent to an injection of 24.9 pounds of the preservative per cubic foot, and it was thought unnecessary from a practical standpoint to go above this point.

After the proper quantities of preservative had been placed in 50-c. c. glass-stoppered bottles, these were sealed and sterilized in exactly the same way as the agar bottles and along with them.

As a few experimental weighings before and after sterilization indicated that no loss occurred, even of such volatile substances as are contained in the lowest fractions of coal-tar creosote, the method may be considered safe.

After sterilization, both the agar and preservative bottles were heated on the water bath, then transferred to a sterile culture case (Pl. I, fig. 2), where the hot agar was poured into the preservative bottle and thoroughly mixed. In some cases one or two sterile glass beads were added to the preservative bottles to facilitate the mixing. These were removed later.

The agar-preservative mixtures were then poured into sterile Petri dishes 100 mm. in diameter and 10 mm. deep. After cooling, each plate was inoculated at the center with a weft of mycelium 5 or 6 mm. square, cut from a Petri-dish culture (Pl. I, fig. 3) 2 to 3 weeks old of the fungus desired, either *Fomes annosus* Fr. or *Fomes pinicola* (Sw.) Fr. The dishes thus prepared were then placed in an incubator and held at approximately 25° C. for periods varying from 4 to 10 weeks, usually from 4 to 6.

[1] A series consists of a set of progressively increasing concentrations of a given preservative, tested at the same time against the action of a single fungus.

In addition to the possibility, in some instances, of chemical combinations between the preservative and the media, there will also necessarily be a slight change in concentration, due to the drying out of the media when held in Petri dishes for six to eight weeks. Likewise, during this interval of time certain volatile constituents, particularly the lighter oils, may escape from the media.

In recording observations of the behavior of the fungi toward the preservative, rapidity and amplitude of growth, together with any other peculiarities in appearance, were noted, inspection being made about once a week.

One very interesting feature of the tests was the development of a "halo" around either the living or the dead transfers, or in advance of the fungous growth on the check cultures. These halos differed in appearance on the different preservatives, sometimes being lighter, sometimes darker, than the surrounding medium. In order to determine whether the change was due to advance submerged hyphæ, several transfers were made from the halos to fresh sterile agar, but as no living organisms were demonstrated by this test or by microscopical examination to be present it appears to be an advance physicochemical change in the media, arising, perhaps, from the diffusion of enzyms from the transfer, as Kellerman (15) has recently demonstrated for cytase produced in fungus cultures.

DEVELOPMENT OF FOMES ANNOSUS AND FOMES PINICOLA.

IN NONTOXIC CHECK CULTURES.

In the check cultures, *Fomes annosus* produces a rather compact creamy growth (Pl. II, fig. 20, and Pl. IV, fig. 48), forming an abundance of the characteristic conidia described by Brefeld. *F. pinicola* (Pl. I, fig. 4; Pl. III, fig. 31; and Pl. IV, fig. 40), on the other hand, develops a fluffy, deep, white mycelium of considerably more rapid growth than *F. annosus*. At 25° C., *F. pinicola* develops a radial growth of 24 mm. in 9 days (average of 14 tests) and covers the plate in 15 days (15 tests); *F. annosus* develops 15 mm. in 8⅗ days (19 tests) and covers the plate in 20½ days (12 tests).

IN CULTURES CONTAINING TOXIC SUBSTANCES.

The rate of growth of each of these two fungi on toxic media is usually considerably retarded, in many cases strongly so, as compared with check cultures. In some instances where very low concentrations of certain substances are used, a stimulating effect is observed, but this condition is reversed with increased concentrations. The stimulated growth on zinc-chlorid concentrations when heated in the presence of the culture media (such concentrations often being far above those necessary to kill when not so heated together) is

readily explained on the basis of chemical combination with the media.

The length of time required to make an initial growth on different toxic media varies from a very few days up to seven weeks or more; check cultures usually start within two or three days. Table I illustrates this for a few preservatives.

TABLE I.—*Time required by Fomes annosus on 0.2 per cent concentrations and F. pinicola on 0.1 per cent concentrations to make initial growth from mycelium at 25° C.*

Preservative used.	F. annosus.	F. pinicola.
	Days.	*Days.*
Check cultures	2 to 3	2 to 2
Sodium fluorid	20	24
Coal-tar creosote	18	21
Coal-tar creosote, Fraction II	15	18
Coal-tar creosote, Fraction III	40	23
Coal-tar creosote, Fraction IV	......	53

It is thus seen that no growth demonstrable to the naked eye on any of the concentrations mentioned occurred within a period of two weeks, and the error which would occur in discontinuing the tests at the end of 8 to 10 days, as several investigators have done, becomes very evident.

RECORD OF TESTS CONDUCTED.

A description of each of the 18 preservatives used, accompanied by individual tables and notes showing the rate, amplitude, and appearance of growth on the different concentrations, as compared with the check cultures, is given on the following pages. Under the heading "Concentration of the preservative" in each table the average radial distance to which the fungus has grown from the margin of the transfer at the end of the test is indicated by numerals,[1] the position of the first zero marking the killing point: Thus, 4 = 30 to 40 mm.; 3 = 20 to 30 mm.; 2 = 10 to 20 mm.; 1 = 1 to 10mm.; 0 = no growth.

Sodium fluorid.

[Laboratory sample No. 1929. Purchased from Eimer & Amend, Chicago, Ill.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).					
	Number.	Duration.		0.05	0.1	0.15	0.2	0.25	Check.
		Weeks.							
Fomes annosus	9	4	1	4	3	2	1	0	4
F. pinicola	11	5 to 7	1	3	2	0	......	......	4

[1] It should be kept in mind that the growth rate designated as "4" is not necessarily the same on different preservatives or different concentrations of the same preservative. All cultures which have produced a growth of at least 30 to 40 mm. radius at the end of the test are included. Some of these may have reached this point in two to three weeks, as in the case of the checks, while others may have required the full test period; hence, the data as presented show only the relative retarding effect of the higher concentrations.

Fomes annosus: In one week, the radial growth of the check was 15 mm.; 0.05 per cent, 20 mm.; 0.1 per cent, 15 mm.; 0.15 per cent, 3 mm. In four weeks concentrations up to 0.15 per cent showed 20 to 30 mm.; 0.2 per cent, about 2 mm. Thus, the rate of growth on 0.05 and 0.1 per cent concentrations equaled or exceeded that of the checks, but the higher concentrations produced a decided inhibition. The growth on the toxic media appeared very much as on the check.

Fomes pinicola: In two weeks, the radial growth of the check was 40 mm.; 0.05 per cent, 9 mm.; 0.1 per cent, 4 mm.; no growth on 0.15 per cent. After four to six weeks, no growth on 0.15 per cent. The growth on the toxic media was fluffy, white, and quite similar in appearance to that on the check.

Zinc chlorid.

(Pl. IV, figs. 53 and 54.)

[Laboratory sample No. 2239. Cooperator, Grasselli Chemical Co., Cleveland, Ohio. Commercial salt, meeting the specifications of the American Railway Engineering and Maintenance-of-Way Association.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).											
	Number.	Duration.		0.1	0.2	0.3	0.4	0.45	0.475	0.5	0.6	0.65	0.7	0.75	Check.
		Weeks.													
Fomes annosus	33	5 to 8	1	4	1	1	1	1	1	0	....	......	......	......	4
F. pinicola	33	4 to 8	2	....	....	....	....	....	......	....	4	4	4	0	4

Fomes annosus: In 18 days, the radial growth of the checks reached about 35 mm.; 0.05 per cent, about equal to check; 0.15 per cent, 8 mm.; 0.3 per cent, 1 mm. There was usually no growth on higher concentrations until after about four weeks, and it was comparatively slight even after six to eight weeks, reaching only 1 to 8 mm. The toxic cultures generally were denser and of brighter tan color than the check.

Fomes pinicola: In two weeks, the radial growth of the check reached 40 mm.; 0.6 and 0.7 per cent, 10 mm. After four weeks, 0.6 and 0.7 per cent reached 35 mm. On the lower concentrations the growth was more fluffy than that on the check.

Sapwood antiseptic.

[Laboratory sample No. 1611. Cooperator, J. M. Long, Chicago, Ill. Formula (by weight, in water solution): NaCl, 2.92 per cent; $CaSO_4$, 0.246 per cent; $ZnSO_4+7\ H_2O$, 0.246 per cent; $CuSO_4+5\ H_2O$, 0.182 per cent; $FeSO_4+4\ H_2O$, 0.0605 per cent.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).						
	Number.	Duration.		16⅔	25	30	50	60	75	Check.
		Weeks.								
Fomes annosus	17	4 to 5	....	4	4	3	2	2	1	4

Fomes annosus: In about three weeks the radial growth of check reached 40 mm.; 50 per cent, 10 to 15 mm.; 75 per cent, very slight growth. Penicillium developed abundantly on 100 per cent. The preservative up to 25 per cent concentration showed a decided stimulating effect.

The first concentration is based on the solution, as given above, which was prepared and submitted by the cooperator. Above 16⅔ per cent it was necessary to use a more concentrated solution, and a strength six times the original formula was prepared.

Coal-tar creosote, grade C.

(Pl. I, figs. 5 to 9.)

[Laboratory sample No. 1074. Purchased from the Creosote Supply Co., Chalmette, La. Liquid at room temperature, 8.4 per cent water; specific gravity, 1.0483 at 60° C.; flash point, 93° C.; burning point, 100° C.; 11 per cent distills below 205° C.; 54.1 per cent distills below 275° C.; 74.1 per cent distills below 320° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).											
	Number.	Duration.		0.075	0.125	0.175	0.2	0.225	0.3	0.35	0.4	0.45	0.5	0.55[1]	Check.
		Weeks.													
Fomes annosus	44	4 to 8	1	....	....	....	2	1	1	1	1	1	1	0	4
F. pinicola	21	4 to 6	1	3	2	1	1	0	....	....	....	....	....	....	4

[1] These values are based on gum-arabic emulsions. Later work, using the pure preservative, indicates that the toxic point may fall somewhat lower.

Fomes annosus: In 17 days the radial growth of the check reached about 40 mm.; 0.2 and 0.275 per cent showed initial growth only. In three to four weeks, 0.2 per cent showed 10 mm.; 0.25 to 0.5 per cent, 2 to 3 mm. In six weeks, 0.525 per cent showed only initial growth. In seven weeks, 0.5 and 0.525 per cent reached 2 to 9 mm. The growth on the toxic media was about the same in appearance as on the check.

Fomes pinicola: In two weeks the radial growth of the check reached about 40 mm.; 0.075 per cent, 3 mm.; no growth above this point. In four weeks, 0.075 per cent showed 25 mm.; 0.1 per cent, 13 mm.; 0.15 per cent, 6 mm. After five weeks, 0.175 and 0.2 per cent reached 3 mm.; above this point all growth was inhibited. The growth on the toxic media was dull white, with a crinkled edge.

Coal-tar creosote, Fraction I.

(Pl. II, figs. 10 and 11.)

[Laboratory sample No. 1094. Cooperator, Semet-Solvay Co., Ensley, Ala. Light liquid at room temperature; specific gravity, 0.934 at 60° C.; flash point, 62° C.; burning point, 69° C.; 78.3 per cent distills below 215° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).					
	Number.	Duration.		0.2	0.225	0.25	0.275	0.3	Check.
		Weeks.							
Fomes annosus	33	4 to 6	3	4	4	2	1	0	4
F. pinicola	13	4 to 6	1	4	0	......	......	......	4

Fomes annosus: In 10 to 14 days the radial growth of the check reached 20 mm.; 0.2 to 0.25 per cent, from 1 to 4 mm. In four weeks, 0.2 to 0.225 per cent reached 30 mm.; 0.25 to 0.275 per cent, from 7 to 10 mm.; no growth at 0.3 per cent. The toxic cultures produced a thin, stringy growth.

Fomes pinicola: In two weeks the radial growth of the check reached 40 mm.; 0.2 per cent, 1 mm. In four weeks, 0.2 per cent reached 40 mm.; no growth above this point. The toxic cultures produced a fluffy white growth, similar in appearance to that on the check.

Coal-tar creosote, Fraction II.

(Pl. II, figs. 12 and 13.)

[Laboratory sample No. 1106. Cooperator, Semet-Solvay Co., Ensley, Ala. Naphthalene odor; nearly solid at room temperature; specific gravity, 1.003 at 60° C.; flash point, 79° C.; burning point, 85° C.; 9 per cent distills below 205° C.; 95.9 per cent distills below 287° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).						
	Number.	Duration.		0.1	0.125	0.15	0.175	0.2	0.225	Check.
		Weeks.								
Fomes annosus	20	5 to 9	1	......	3	2	1	1	0	4
F. pinicola	18	4 to 5	2	4	4	0	......	......	......	4

Fomes annosus: In two weeks the radial growth of the check reached 20 mm.; no growth on 0.15 per cent and above. In four weeks, no growth on 0.225 per cent. In six weeks, 0.15 per cent reached 12 mm.; 0.2 per cent, 6 mm.; no growth on 0.225 per cent. The growth on the toxic media was compact and creamy in color.

Fomes pinicola: In two weeks the radial growth of the check reached 40 mm.; no growth on 0.125 per cent. In four weeks 0.1 and 0.125 per cent reached 40 mm.; no growth above this point. The growth on the toxic media was a dingy white and less fluffy than that on the check.

Coal-tar creosote, Fraction III.

(Pl. III, fig. 30.)

[Laboratory sample No. 1107. Cooperator, Semet-Solvay Co., Ensley, Ala. Liquid at room temperature; specific gravity, 1.045 at 60° C.; flash point, 103° C.; burning point, 110° C.; 0.9 per cent distills below 215° C.; 4.7 per cent distills below 275° C.; fraction from 170° to 245° C. more or less solid with naphthalene.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).									
	Number.	Duration.		0.05	0.075	0.1	0.125	0.15	0.2	0.25	0.3	0.325 [1]	Check.
		Weeks.											
Fomes annosus	60	4 to 12	2	....	....	....	....	1	1	1	1	0	4
F. pinicola	14	4 to 7	1	3	2	1	0	....	....	....	....	....	4

[1] The radial growth of *Fomes annosus* on concentrations above 0.2 per cent is very slight, usually not exceeding 1 mm., and the actual toxic point is difficult to locate. It lies between 0.25 and 0.35 per cent.

Fomes annosus: In 19 days the radial growth of the check reached 40 mm.; 0.15 and 0.175 per cent, 1 or 2 mm. In five to six weeks 0.3 per cent showed 1 mm. and lower concentrations 1 to 5 mm. The growth on the toxic media was creamy and slightly lighter than that on the check.

Fomes pinicola: In two weeks the radial growth of the check reached 40 mm. In about one month 0.05 per cent showed 3 mm.; 0.075 per cent, 2 mm. In about seven weeks 0.1 per cent showed initial growth; lower concentrations from 16 to 23 mm. The growth on the toxic media was a fluffy white on the lower concentrations; denser on 0.1 per cent.

Coal-tar creosote, Fraction IV.

(Pl. II, figs. 14 to 19.)

[Laboratory sample No. 1108. Cooperator, Semet-Solvay Co., Ensley, Ala. Liquid at room temperature; specific gravity, 1.088 at 60° C.; flash point, 130° C.; burning point, 136° C.; 0.9 per cent distills below 245° C.; 54.3 per cent distills below 320° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).											
	Number.	Duration.		0.025	0.05	0.075	0.1	0.125	0.2	0.9	1	2	3	3.3 [1]	Check.
		Weeks.													
Fomes annosus	75	5 to 12	1	....	....	....	....	....	2	2	1	1	1	0	4
F. pinicola	23	5 to 8	1	3	2	2	1	0	....	....	....	....	....	....	4

[1] The growth of *Fomes annosus* on concentrations above 2 per cent is very slight, usually not exceeding 1 mm. in six weeks, and the actual toxic point is difficult to locate. It lies between 2.5 and 3.5 per cent.

Fomes annosus: In 12 days, the radial growth of the check reached 25 mm.; very slight growth on 0.2 to 0.5 per cent. In 18 days, 0.8 to 3 per cent reached 1 to 4 mm. In four weeks, 1.25 to 3 per cent reached 1 to 5 mm. The growth on the toxic media was usually darker than on the check.

Fomes pinicola: In two weeks, the radial growth of the check reached 40 mm.; no growth on 0.025 per cent. In four weeks, 0.025 per cent showed 2 mm.; no growth on higher concentrations. In eight weeks, 0.025 per cent reached 25 mm.; 0.05 per cent, 15 mm.; 0.075 per cent, 10 mm.; 0.1 per cent, 2 mm.; no growth above this point. The growth on the toxic cultures was dull, compact, and crinkled.

Coal-tar creosote, Fraction V.

(Pl. II, figs. 21 to 24.)

[Laboratory sample No. 1109. Cooperator, Semet-Solvay Co., Ensley, Ala. Heavy, tarry liquid; specific gravity, 1.150 at 60° C.; flash point, 172° C.; burning point, 178° C.; 10.1 per cent distills below 320° C.; 63.3 per cent distills below 380° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).								
	Number.	Duration.		0.1	0.5	1	7	7.8	8	30	33 [1]	Check.
		Weeks.										
Fomes annosus	42	4 to 9	0	4	3	2	2	......	1	1	0	4
F. pinicola	30	4 to 8	0	......	......	2	1	0	......	......	......	4

[1] These values are based on gum-arabic emulsions.

Fomes annosus: In 10 to 14 days, the radial growth of the check reached about 40 mm.; 5.5 to 30 per cent showed 1 to 4 mm. In four weeks, 5.5 to 7.5 per cent reached 8 to 15 mm.; 15 and 25 per cent, 2 mm.; no growth on 20 per cent gum-arabic emulsion. The growth on the toxic media was dense and creamy on the lower concentrations; submerged at first on the higher concentrations.

Fomes pinicola: In two weeks, the radial growth of the check reached 40 mm.; in three weeks, 1 to 2 per cent showed initial growth; in four weeks, 3 to 6.5 per cent showed first growth; after eight weeks, 4.5 to 5 per cent reached 10 to 20 mm. The growth on the lower concentrations of the toxic media was white and fluffy; on the higher concentrations it was tawny and radiate, with a crinkled edge.

Avenarius carbolineum.

[Laboratory sample No. 1843. Cooperator, Carbolineum Wood Preserving Co., Milwaukee, Wis. Thick liquid at room temperature; specific gravity, 1.126 at 16.5° C.; flash point, 139° C.; burning point, 166° C.; 1.1 per cent distills below 215° C.; 6.1 per cent distills below 275° C.; 1.91 per cent tar acids.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).								
	Number.	Duration.		0.175	0.275	0.3	0.8	1	4	5	5.25	Check.
		Weeks.										
Fomes annosus	53	4 to 10	1	......	......	2	2	1	1	1	0	4
F. pinicola	18	5 to 6	2	1	1	0	....	....	....	....	......	4

Fomes annosus: In 18 days, the radial growth of the check reached nearly 40 mm.; 0.3 per cent, 17 mm.; higher concentrations up to 4 per cent showed 1 to 6 mm. In four to six weeks, 5 per cent reached 1 mm. The growth on the toxic media was similar in appearance to that on the check.

Fomes pinicola: In two weeks the radial growth of the check reached 40 mm.; 0.175 per cent showed no growth. In four weeks, 0.175 to 0.275 per cent reached 1 mm. The growth on the toxic media was compact and darker than that on the check.

S. P. F. carbolineum.

(Pl. III, fig. 29.)

[Laboratory sample No. 1844. Cooperator, Bruno-Grosche & Co., New York, N. Y. Thick brown liquid, specific gravity, 1.127 at 16° C.; flash point, 133° C.; burning point, 157° C.; less than 9 per cent distills below 245° C.; about 30 per cent distills below 320° C.; 2.42 per cent tar acids.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).							
	Number.	Duration.		1	1.5	1.75	2	3	4	4.5 [1]	Check.
		Weeks.									
Fomes annosus	73	5 to 8	2	1	1	1	1	1	1	0	4

[1] The growth of *Fomes annosus* on concentrations above 3 per cent is very slight, usually not exceeding 1 mm. in six weeks, and the actual toxic point is difficult to locate. It lies between 4 and 5 per cent.

Fomes annosus: In four weeks the radial growth of the check reached about 40 mm.; 1 and 1.5 per cent, 1 mm. In six weeks, 1 and 1.5 per cent showed 5 mm.; 1.75 to 4 per cent, 1 to 5 mm. Tests were not made on concentrations below 1 per cent. The growth on the toxic media was quite similar in appearance to that on the check.

Water-gas tar distillate.

(Pl. III, figs. 27 and 28.)

[Laboratory sample No. 2235. Cooperator, United Gas Improvement Co., Philadelphia, Pa. Greenish brown liquid; specific gravity, 0.995 at 60° C.; flash point, 81° C.; burning point, 93° C.; 3.3 per cent distills below 180° C.; 61.7 per cent distills below 275° C.; 80.3 per cent distills below 320° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).									
	Number.	Duration.		0.1	0.2	0.3	0.35	0.4	0.45	0.5	0.6	0.65	Check.
		Weeks.											
Fomes annosus	58	5 to 8	0	4	3	2	2	1	1	1	1	0	4

Fomes annosus: In 12 days the radial growth of the check reached 15 mm.; 0.1 per cent, 2 mm. In three weeks, 0.1 per cent showed about 20 mm.; 0.2 per cent, 5 mm. In six weeks, 0.2 per cent reached 17 mm.; 0.25 per cent, 15 mm.; 0.3 per cent, 5 mm.; 0.35 to 0.6 per cent, from 1 to 12 mm. The growth on the toxic media was of a brighter creamy appearance than that on the check.

United Gas Improvement Co. 1.07 oil (water-gas tar distillate).

(Pl. III, figs. 25 and 26.)

[Laboratory sample No. 1101. Cooperator, United Gas Improvement Co., Philadelphia, Pa. Mobile, oily liquid, with kerosene odor; specific gravity, 1.058 at 60° C.; flash point, 48° C.; burning point, 65° C.; 9.04 per cent distills below 205° C.; 24.24 per cent distills below 315° C.; 67.9 per cent distills below 378° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).										
	Number.	Duration.		0.1	3	3.5	5	6	6.5	10	25	30	40	Check.
		Weeks.												
Fomes annosus	31	4 to 8	....	4	4	3	2	....	....	2	1	1	1	4
F. pinicola	22	4 to 5	....	....	2	2	2	2	1	....	1	....	1	4

Fomes annosus: In 10 to 14 days, the radial growth of the check reached 28 mm.; 40 and 50 per cent, 2 mm. In four to six weeks, 40 and 50 per cent showed nearly 10 mm. The growth on the toxic media appeared denser and of a brighter tan color than that on the check.

Fomes pinicola: In two weeks, the radial growth of the check reached almost 40 mm.; 3 to 29 per cent, 2 to 7 mm. In four to five weeks all concentrations between 3 and 40 per cent showed 2 to 15 mm. The growth on the toxic media appeared velvety, compact, and creamy, while that on the check was a fluffy white.

Wood tar (hardwood).

(Pl. IV, figs. 41–47.)

[Laboratory sample No. 1561. Cooperator, Marden, Orth & Hastings, Chicago, Ill. Black, viscous liquid, with pyroligneous odor; specific gravity, 1.195 at 60° C.; flash point, 90° C.; contains 24 per cent water; 11.7 per cent distills below 105° C.; 50.9 per cent distills below 244° C.; decomposition occurs above 230°.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).							
	Number.	Duration.		0.2	0.5	0.7	0.75	0.9	1	1.25[1]	Check.
		Weeks.									
Fomes annosus	50	4 to 6	0	......	4	......	4	4	2	0	4
F. pinicola	30	4 to 5	1	4	4	4	0	......	....	......	4

[1] Based on gum-arabic emulsions.

Fomes annosus: In 9 to 10 days, the radial growth of the check reached 12 mm.; 0.5 to 0.8 per cent, 1 to 2 mm. In two to four weeks the check reached 40 mm. and concentrations up to 1 per cent showed 10 to 35 mm. The growth on the toxic media was dark creamy and somewhat denser than that on the check.

Fomes pinicola: In two weeks the radial growth of the check reached 40 mm.; 0.5 per cent, 10 mm.; no growth above this. In four to five weeks 0.2 to 0.7 per cent showed 40 mm.; 0.725 per cent, 10 mm.; no growth on higher concentrations. The growth on the toxic media was luxuriant, white, and fluffy.

Wood creosote (Douglas fir).

(Pl. III, figs. 32–37.)

[Laboratory sample No. 1099. Cooperator, Logged-Off Land Utilization Co., Seattle, Wash. Black liquid, with a strong pyroligneous odor; specific gravity, 1.052 at 60° C.; flash point, 45° C.; burning point, 85° C.; contains 8.35 per cent water; 7.55 per cent distills below 100° C.; 54.69 per cent distills below 245° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).									
	Number.	Duration.		0.1	0.125	0.15	0.2	0.25	0.4	0.45	0.6	0.65[1]	Check.
		Weeks.											
Fomes annosus	55	4 to 7	0	4	......	3	3	2	2	1	1	0	4
F. pinicola	26	4 to 6	0	4	4	4	0	......	......	......	......	......	4

[1] These values are based on gum-arabic emulsions.

Fomes annosus: In 11 days the radial growth of the check reached 25 mm.; 0.15 to 0.30 per cent reached 3 to 6 mm. In 15 days, 0.1 per cent showed 30 mm. In four weeks, 0.15 to 0.30 per cent reached 18 to 28 mm. Usually, from four to six weeks were required for initial growth on 0.6 to 0.625 per cent. The growth on the toxic media was dense, dark creamy, occasionally zonate.

Fomes pinicola: In eight days the radial growth of the check reached 15 mm.; 0.025 to 0.075 per cent, 11 to 20 mm. In three weeks, 0.025 to 0.1 per cent covered the plates; 0.125 per cent reached 17 mm.; 0.15 per cent 4 mm. In 34 days the initial growth appeared on 0.175 per cent. The growth on the toxic media up to 0.125 per cent was white and luxuriant, exceeding that on the check.

Cresol calcium.

(Pl. III, figs. 38 and 39.)

[Laboratory sample No. 2086. Cooperator, Blagden, Waugh & Co., London, England.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).		
	Number.	Duration.		0.14	0.28	Check.
		Weeks.				
Fomes annosus	8	4 to 7	1	4	0	4

Fomes annosus: In about two weeks the radial growth of the check reached 20 mm.; 0.14 per cent, 3 mm. After three weeks the check showed 30 mm.; 0.14 per cent, 11 mm. After six weeks, 0.14 per cent reached 30 mm.; no growth on 0.28 per cent. The growth on the toxic media occurred in alternating light and dark zones.

A diversion from the usual method of weighing the preservative was necessary with this substance, since on sterilizing at 100° C. the preservative would form a hard crust on the sides of the bottles. To obviate this difficulty, the average weight of a drop from a small pipette was obtained (four tests). This was found to be 28 milligrams, the drops varying not over 2 or 3 milligrams. The preservative was then added directly to the media bottles in quantities of one, two, three, or four drops, the killing point lying between one and two drops, which corresponds to 0.14 and 0.28 per cent, respectively.

Copperized oil.

(Pl. IV, figs. 49 to 51.)

[Laboratory sample No. 1095. Cooperator, Ellis-Foster Co., New York, N. Y. Probably a crude petroleum containing a slight amount of copper and sufficient vegetable oil to form a homogeneous solution; specific gravity, 0.937 at 25° C.; flash point, 125° C.; burning point, 164° C.; less than 0.2 per cent distills below 215° C.; 30.2 per cent distills below 320° C.; about 80 per cent distills below 360° C.; copper content, 0.34 per cent.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).							
	Number.	Duration.		3	5	15	30	33	36	40	Check.
		Weeks.									
Fomes annosus	40	4 to 9	1	4	4	3	2	2	2	0	4
F. pinicola	25	4 to 6	1	4	4	4	....	....	....	4	4

Fomes annosus: In 18 to 22 days the radial growth of the check reached 40 mm.; the toxic concentrations up to 6.25 per cent showed the same growth, except that the check was denser. In about three weeks 15 to 30 per cent reached 1 to 11 mm. In nine weeks, 30, 33, and 36 per cent showed 12 to 20 mm. On the less toxic media alternating zones of lighter superficial growth and darker submerged growth occurred. On the high concentrations either a black submerged growth or a light-brown superficial growth appeared.

Fomes pinicola: In two weeks the radial growth of the check reached 40 mm.; 15 to 26 per cent, 20 to 27 mm.; 40 per cent, 2 mm. In six weeks all concentrations up to 40 per cent reached about 40 mm. The growth on the toxic media was fluffy, but darker than that on the check.

None-Such Special.

(Pl. IV, fig. 52.)

[Laboratory sample No. 2696. Cooperator, George M. Saums Co., Trenton, N. J. Yellow, oily liquid with strong varnish or paint odor; claimed by the manufacturers to waterproof and give a hard finish to timber, as well as prevent or stop decay; chemical composition unknown to us.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).								
	Number.	Duration.		1	5	15	25	30	35	40	45	Check.
		Weeks.										
Fomes annosus	28	4	....	4	4	4	4	4	4	4	4	4
F. pinicola	29	3 to 4	....	4	4	4	4	4	4	4	....	4

Fomes annosus: In 10 to 14 days the radial growth of the check reached 20 mm.; concentrations from 5 to 45 per cent showed approximately 40 mm. The preservative appears to exert a nutritive or stimulative effect, rather than any toxic action, although the fungus will not grow on the pure preservative. The growth on the treated media is dark and submerged, rising to the surface later to form a very dense creamy mycelium.

Fomes pinicola: In eight days the radial growth of the check reached about 30 mm.; 0.25 to 3 per cent, 15 to 20 mm. In two to three weeks 35 to 50 per cent showed 20 to 40 mm. The growth on all concentrations up to 50 per cent almost equaled that on the check.

DISCUSSION OF TESTS.

Table II gives the results of investigations in our laboratory in the use of such preservatives as have been sufficiently checked to permit statements regarding their toxicity to the fungi noted under

the test conditions outlined. In this table the preservatives are arranged in the order of their toxicity, beginning with the most toxic.

TABLE II.—*Killing point of Fomes annosus and F. pinicola for the various preservatives, compared with coal-tar creosote, No. 1074, and zinc chlorid, No. 2239.*

[Results marked with an asterisk (*) were not checked in duplicate, but they are approximately correct.]

Fungus and preservative.	Killing point. Per cent.	Killing point. Pounds per cubic foot.	Ratio to creosote.	Ratio to zinc chlorid.
Fomes annosus (creosote killing point, 0.55 per cent; zinc-chlorid killing point, 0.5 per cent):				
Coal-tar creosote, Fraction II	0.225	0.140	2.5	2.2
Sodium fluorid	.25	.156	2.2	2
Cresol calcium [1]	0.14-.28	0.087-.175	3.9-1.9	3.6-1.8
Coal-tar creosote, Fraction I	.30	.187	1.8	1.7
Coal-tar creosote, Fraction III	*.325	.203	1.7	1.5
Zinc chlorid	.50	.312	1.1	1
Coal-tar creosote, grade C	.55	.343	1	.91
Water-gas tar distillate No. 2235 (specific gravity 0.995)	*.65	.405	.84	.76
Wood creosote (Douglas fir)	*.65	.405	.84	.76
Wood tar (hardwood)	*1.25	.78	.44	.40
Coal-tar creosote, Fraction IV	*3.30	2.06	.16	.15
S. P. F. carbolineum	4.5	2.8	.12	.11
Avenarius carbolineum	5.25	3.27	.104	.095
Coal-tar creosote, Fraction V	*33	20.59	.017	.015
Copperized oil	40	25	.014	.013
United Gas Improvement Co. 1.07 oil, No. 1101	40+	25+	.014-	.013-
None-Such Special	40+	25+	.014-	.012-
Sapwood antiseptic	75+	....	.007-	.007
Fomes pinicola (creosote killing point, 0.225 per cent; zinc-chlorid killing point, 0.75 per cent):				
Coal-tar creosote, Fraction III	.125	.078	1.8	6
Coal-tar creosote, Fraction IV	*.125	.078	1.8	6
Coal-tar creosote, Fraction II	.15	.094	1.5	5
Sodium fluorid	.15	.094	1.5	5
Wood creosote (Douglas fir)	*.20	.125	1.12	3.8
Coal-tar creosote, Fraction I	.225	.140	1	3.3
Coal-tar creosote, grade C	.225	.140	1	3.3
Avenarius carbolineum	.30	.187	.75	2.5
Zinc chlorid	.75	.468	.30	1
Wood tar (hardwood)	.75	.468	.30	1
Coal-tar creosote, Fraction V	*7.8	4.87	.029	.096
Copperized oil	40+	25+	.0056-	.019-
United Gas Improvement Co. 1.07 oil, No. 1101	40+	25+	.0056-	.019-
None-Such Special	50+	31.2+	.0045-	.0015-

[1] Killing point lies between the limits given (1 and 2 drops of the preservative in 20 c. c. of the medium).

Table II shows that of the 18 preservatives tested against *Fomes annosus* 6 totally inhibit growth at or below 0.5 per cent, 5 between 0.5 and 3.5 per cent, 1 at 4.5 per cent, 1 at 5.25 per cent, and the remaining 5 show extremely low toxic properties, requiring from 33 to 75 per cent.

Sodium fluorid is particularly toxic, being slightly more than twice as effective as zinc chlorid.

Cresol calcium in these tests shows a high toxicity, and the poor results reported against it in service tests [1] are apparently due to a change in chemical constitution or to leaching, which did not take place under our method of testing.

[1] Unpublished report, Forest-Products Laboratory.

The three lower boiling fractions of coal-tar creosote are highly toxic, exceeding the creosote itself. Fraction IV is only about one-sixth as toxic as creosote. Fraction V, consisting of the last heavy residues, of which only 10 per cent distills below 320° C., is extremely low in toxicity, with a killing concentration of about 33 per cent.

Wood creosote, derived from the destructive distillation of Douglas fir, compares very favorably with coal-tar creosote, notwithstanding its water content of over 8 per cent.

Hardwood tar shows moderate antiseptic properties, proving about one-half as toxic as the softwood creosote.

The two carbolineums are much less toxic than the creosotes tested.

Water-gas tar distillate of low specific gravity appears to be slightly less toxic than coal-tar creosote, while the heavier distillate, represented by United Gas Improvement Co. 1.07 oil, is so low in toxic properties as to appear to be of little value in wood preservation.

The secret product None-Such Special appears to be more nutrient than antiseptic to fungi, so far as these tests indicate; however, the physical properties of the substance when injected into wood may be such as to exclude fungous growth and thus to substantiate the claims made for it. Durability tests on treated wood are highly desired.

Zinc chlorid has a killing point almost identical with coal-tar creosote.

Table II also shows that of 14 preservatives tested against *Fomes pinicola* 8 totally inhibit growth below 0.5 per cent, 2 between 0.5 and 1 per cent, 1 at about 7.8 per cent, and the remaining 3 require over 40 per cent.

Sodium fluorid and coal-tar creosote Fractions II, III, and IV are all extremely toxic to this fungus, the killing points being almost identical.

Coal-tar creosote Fraction I and wood creosote are about three-fourths as toxic as the above; Avenarius carbolineum is about one-half as toxic.

Zinc chlorid in the *Fomes pinicola* list stands only tenth in efficiency, whereas in the *F. annosus* list it stands in fifth place.

The last four preservatives show very low antiseptic properties toward *Fomes pinicola*, as they did toward *F. annosus*.

By comparing the behavior of the two fungi toward the same chemical substances a marked difference will be observed. With the exception of zinc chlorid and copperized oil, *Fomes annosus* is a far more resistant organism than *F. pinicola*, the ratio running as high as 26 to 1 in the case of Fraction IV of coal-tar creosote.

It has often been noted during the course of the experiments that *Fomes annosus*, after a considerable lapse of time, can accommodate itself to rather high concentrations of certain preservatives. Its

normal growth is also relatively slow as compared with that of the other organism. Sometimes on high concentrations of toxic media the fungus would remain dormant from four to seven weeks and then begin a slow development. For this reason it has been difficult in many cases to find the exact inhibition point of a preservative without carrying out a large number of long-continued tests.

On the other hand, *Fomes pinicola* seems rather sensitive to slight changes in concentration, and one can usually judge within a month whether the fungus will develop.

The difference in behavior between these two organisms shows how very necessary it is to make only qualified statements when discussing the relative toxicity of preservatives toward fungi. We have at present no satisfactory way of predicting, except by trial, how a given preservative will react on different organisms.

A direct comparison of toxicities, as given in Table II, shows that in many cases essentially the same order holds, but there are several exceptions, Fractions I and IV of coal-tar creosote and zinc chlorid being the most conspicuous.

In Table III the oils used are grouped according to their nature, in order to show a direct comparison between wood tar, coal tar, water-gas tar, and petroleum products.

TABLE III.—*List of wood-preserving oils tested, showing relation between their specific gravities, boiling points, and toxic properties.*

[Results marked with an asterisk (*) are approximately correct.]

Preservative.	Specific gravity.[1]	Percentage distilling below—							Killing point (per cent).	
		180° C.	215° C.	245° C.	275° C.	305° C.	320° C.	360° C.	Fomes annosus.	Fomes pinicola.
Wood tar (hardwood)	1.195	*27	*31	51	......	......	......	......	*1.25	0.75
Wood creosote (Douglas fir)	1.052	*16	*31	54.7	......	......	......	......	*.65	*.20
United Gas Improvement Co. 1.07 oil, No. 1101	1.058	*7	*10	......	16.3	*22	*27	56.4	40+	40+
Water-gas tar distillate No. 2235	.995	3.3	12.8	37.7	61.7	75.3	80.3	......	*.65	......
Coal-tar creosote:										
Grade C	1.018	4.8	17.8	44.4	54.1	67.2	74.1	......	.55	.225
Fraction I	.934	35.1	78.3	......	......	......	......	......	.30	.225
Fraction II	1.003	*2–3	30	*80	*92	......	......	......	......	......
Fraction III	1.015	......	.9	16.2	49.2	77.7	85	......	*.325	.125
Fraction IV	1.088	......	......	.9	4.7	38.5	54.3	......	*3.30	*.125
Fraction V	1.150	......	......	......	......	4.1	10.1	48.7	*33	*7.8
Avenarius carbolineum (sp. gr. at 16.5° C.)	1.126	......	1.1	2.6	6.1	16.4	*29	......	5.25	.30
S. P. F. carbolineum (sp. gr. at 16° C.)	1.127	......	......	*9	......	......	*30	......	4.5	......
Copperized oil (sp. gr. at 25° C.)	.937	......	*.2	*3	*10	*22	30.2	*80	40	40+

[1] At 60° C. except as stated for the last three preservatives.

It is interesting to note that the wood-tar and low-boiling water-gas tar and coal-tar distillates tested show very similar toxic properties, while the carbolineums, which consist in the main of the high-boiling constituents of coal-tar creosote, in all cases proved much less toxic to the fungi used.

The toxicity of water-gas tar products is highly variable, much more so than commercial coal-tar products. By decreasing the specific gravity the toxicity rapidly increased. The writers do not wish it to be inferred, however, that this necessarily means that water-gas tar and coal-tar products will prove equally efficient under service conditions. The present results are merely suggestive.

The fractionization of coal-tar creosote gives some interesting data. In the case of *Fomes annosus* the three lower fractions proved considerably more toxic than the creosote itself. In the case of *F. pinicola* the four lower fractions were included. In the former case Fraction II gave the best results and in the latter the greater toxicity fell to Fractions III and IV. This indicates that the middle fractions are the most efficient, but to what group of substances the greater toxicity is due we are not yet prepared to state. The work of other investigators with naphthalene, which is one of the principal constituents of Fraction II, would seem at least to militate against this substance.

The high-boiling carbolineums, which approach Fraction IV in their physical and chemical properties, likewise approach it in their toxic properties.

While the higher boiling constituents proved to be less toxic than the lower boiling ones, their greater permanence in wood under service conditions may at least partially offset the lessened toxic efficiency.

The poor showing made by copperized oil against both fungi indicates that adding small amounts of copper in this form to low-toxic petroleum or vegetable oils will produce a mixture of doubtful fungicidal value.

TOXICITY TO FUNGI OF CERTAIN OF THE MORE IMPORTANT PRESERVATIVES.

In order to bring together in convenient form for comparison the results secured by various investigators in the use of certain important preservative substances, as well as those originating in our own laboratory upon the preservatives mentioned, Table IV has been prepared, indicating the salient features of such tests.

In making comparisons, the sources of error as well as the degree of refinement which the figures represent, should be fully considered.

TABLE IV.—*Toxicity of various preservatives to certain wood-destroying and other fungi.*

Toxic substance.	Organism.	Toxic point.	Culture medium.	Duration of test.	Investigator.
A.—INORGANIC COMPOUNDS.					
		Per cent.			
Ammonium chromate [$(NH_4)_2CrO_4$].	Coniophora cerebella.	Under 1	Agar	8 to 10 days.	Falck.
Ammonium fluorid [NH_4F], neutral.	do	Under 0.1	do	do	Do.

TABLE IV.—*Toxicity of various preservatives to certain wood-destroying and other fungi*—Continued.

Toxic substance.	Organism.	Toxic point.	Culture medium.	Duration of test.	Investigator.
A.—INORGANIC COMPOUNDS—con.					
		Per cent.			
Ammonium fluorid	Coniophora cerebella	0.123	Gelatin	4 weeks	Netzsch.
Copper fluorid [CuF_2+2H_2O], pure.	do	Under 0.1	Agar	8 to 10 days	Falck.
Copper silico-fluorid [$CuSiF_6$], pure.	do	Under 0.05	do	do	Do.
Copper sulphate [$CuSO_4+5H_2O$].	do	Under 1	do	do	Do.
Copper sulphate	Molds	3 to 5	Gelatin	14 days	Malenković.
Ferric fluorid [FeF_3]	Coniophora cerebella	0.132	do	4 weeks	Netzsch.
Ferric sulphate [$FeSO_4+7H_2O$].	do	Under 2	Agar	8 to 10 days	Falck.
Ferrous fluorid [FeF_2]	do	0.155	Gelatin	4 weeks	Netzsch.
Hydrofluoric acid [HF], 100 per cent.	do	Under 0.01	Agar	8 to 10 days	Falck.
Hydrofluoric acid	do	0.05	Gelatin	4 weeks	Netzsch.
Hydrofluorsilicic acid [H_2SiF_6].	do	Under 0.05	Agar	8 to 10 days	Falck.
Hydrofluorsilicic acid	do	0.120	Gelatin	4 weeks	Netzsch.
Magnesium silicofluorid [$MgSiF_6+6H_2O$], 95 per cent.	do	Under 0.067	Agar	8 to 10 days	Falck.
Magnesium sulphate [$MgSO_4+7H_2O$].	do	Over 16	do	do	Do.
Mercuric chlorid [$HgCl_2$]	do	Under 0.1	do	do	Do.
Potassium fluorid [KF], pure.	do	Under 0.05	do	do	Do.
Potassium fluorid	do	0.192	Gelatin	4 weeks	Netzsch.
Sodium chlorid [NaCl]	do	Under 10	Agar	8 to 10 days	Falck.
Sodium chlorid	Mold	Over 5	Gelatin	14 days	Malenković.
Sodium fluorid [NaF]	do	2	do	do	Do.
Sodium fluorid, tech. refined.	Coniophora cerebella	Under 0.1	Agar	8 to 10 days	Falck.
Sodium fluorid	do	0.139	Gelatin	4 weeks	Netzsch.
Sodium fluorid, tech	Fomes annosus	0.25	Agar	do	Humphrey and Fleming.
Do	F. pinicola	0.15	do	5 to 7 weeks	Do.
Sodium carbonate [Na_2CO_3].	Coniophora cerebella	Under 0.125	do	10 days	Rumbold.
Sodium silico-fluorid [Na_2SiF_6], about 100 per cent.	do	Under 0.1	do	8 to 10 days	Falck.
Sodium silico-fluorid	do	0.208	Gelatin	4 weeks	Netzsch.
Zinc chlorid [$ZnCl_2$]	do	Under 0.5	Agar	8 to 10 days	Falck.
Zinc chlorid	do	Between 1 and 2.	do	8 days	Rumbold.
Do	Lenzites sepiaria	do	do	do	Do.
Do	Polystictus hirsutus	do	do	do	Do.
Do	P. versicolor	Over 2	do	do	Do.
Zinc chlorid, commercial	Fomes pinicola	0.75	do	4 to 8 weeks	Humphrey and Fleming.
Do	F. annosus	0.5	do	5 to 7 weeks	Do.
Zinc fluorid [ZnF_2]	Coniophora cerebella	0.186	Gelatin	4 weeks	Netzsch.
Acid zinc fluorid, tech	do	Under 0.1	Agar	8 to 10 days	Falck.
Acid zinc fluorid [ZnF_2-HF].	do	0.130	Gelatin	4 weeks	Netzsch.
Zinc silico-fluorid	do	0.159	do	do	Do.
Zinc silico-fluorid [$ZnSiF_6+6H_2O$].	do	Under 0.1	Agar	8 to 10 days	Falck.
Zinc sulphate [$ZnSO_4+7H_2O$].	do	Under 1	do	do	Do.
B.—ORGANIC COMPOUNDS.					
(*a*) *Benzol and phenol derivatives.*					
Anilin [$C_6H_5NH_2$]	Coniophora cerebella	Under 1	Agar	8 to 10 days	Falck.
Cresol [$C_6H_4CH_3OH$]	do	Under 0.125	do	8 days	Rumbold.
Cresol	Lenzites sepiaria	do	do	do	Do.
Do	Polystictus versicolor	do	do	do	Do.
Do	P. hirsutus	Under 0.25	do	do	Do.
Cresol, pure	Penicillium	Under 0.05	do	4 weeks	J. M. Weiss.
Cresol calcium	Coniophora cerebella	Between 1 and 2.	do	8 days	Rumbold.
Do	Lenzites sepiaria	Over 2	do	do	Do.
Do	Polystictus versicolor	Between 1 and 2.	do	do	Do.

TABLE IV.—*Toxicity of various preservatives to certain wood-destroying and other fungi*—Continued.

Toxic substance.	Organism.	Toxic point.	Culture medium.	Duration of test.	Investigator.
B.—ORGANIC COMPOUNDS—continued.					
(*a*) *Benzol and phenol derivatives*—Continued.					
		Per cent.			
Cresol calcium	P. hirsutus	Between 1 and 2.	Agar	8 days	Rumbold.
Do	Fomes annosus	Between 0.14 and 0.28.	do	4 to 7 weeks	Humphrey and Fleming.
Dinitro-p-cresol [$C_6H_2(NO_2)_2CH_3OH$].	Coniophora cerebella.	Under 0.1	do	8 to 10 days	Falck.
Sodium salt of—					
Dinitro-p-cresol, 21 per cent.[1]	do	Under 0.01	do	do	Do.
1:2 dinitro-o-cresol, 31 per cent.[1]	do	Under 0.003	do	do	Do.
4:6 dinitro-m-cresol, 59 per cent.[1]	do	Under 0.005	do	do	Do.
Gallic acid [$C_7H_6O_5+H_2O$]	do	Under 2	do	do	Do.
Gallotannic acid [$C_{14}H_{10}O_4$].	do	Under 1	do	do	Do.
Phenol [C_6H_5OH]	do	Under 0.1	do	do	Do.
Phenol, pure	Penicillium	0.15	do	4 weeks	J. M. Weiss.
O-nitrophenol [$C_6H_4NO_2OH$].	Coniophora cerebella.	Under 0.02	do	8 to 10 days	Falck.
P-nitrophenol	do	Under 0.01	do	do	Do.
Sodium salt of—					
O-nitrophenol, 63 per cent.[1]	do	Under 0.013	do	do	Do.
P-nitrophenol, 60 per cent.[1]	do	Under 0.025	do	do	Do.
2:4 dinitrophenol [$C_6H_3(NO_2)_2OH$].	do	Under 0.01	do	do	Do.
2:4 dinitrophenol, 33 per cent.[1]	do	Under 0.003	do	do	Do.
Salycilic acid [$C_6H_4OHCOOH$].	do	Under 0.1	do	do	Do.
Sodium picrate [$C_6H_2(NO_2)_3ONa$], 40 per cent.[1]	do	Under 0.04	do	do	Do.
Thymol [$C_6H_3CH_3C_3H_7OH$].	do	Under 0.01	do	do	Do.
(*b*) *Tars and creosotes.*					
Coal-tar creosote:					
Straight run, American (sp. gr. 1.049 at 15.5° C.).	Penicillium	0.15	Agar	4 weeks	J. M. Weiss.
5 per cent gum-arabic emulsion.	Polystictus versicolor.	0.25–0.40	do		Dean and Downs.
German (sp. gr. 1.09 at 15° C.).	Molds	0.2	do	4 weeks	J. M. Weiss.
Sp. gr. 1.048 at 60° C.	Fomes pinicola	0.225	do	4 to 6 weeks.	Humphrey and Fleming.
5 per cent gum-arabic emulsion.	F. annosus	0.55	do	do	Do.
German (sp. gr. 1.062 at 38° C.).	Coniophora cerebella.	Under 0.125	do	8 days	Rumbold.
Do	Lenzites sepiaria	Under 0.125	do	do	Do.
Do	Polystictus versicolor.	Under 0.25	do	do	Do.
Do	P. hirsutus	Under 0.25	do	do	Do.
Carbolineum:					
Avenarius (sp. gr. 1.126 at 16.5° C.).	Fomes annosus	5.25	do	4 to 10 weeks	Humphrey and Fleming.
Do	F. pinicola	0.30	do	5 to 6 weeks.	Do.
S. P. F. (sp. gr. 1.127 at 16° C.).	F. annosus	4.5	do	5 to 8 weeks.	Do.
Coal-tar creosote:					
With bases, acids, and solid hydrocarbons removed.	Penicillium	0.85	do	4 weeks	J. M. Weiss.
With 20 per cent tar acids added.	do	0.15	do	do	Do.
With 20 per cent pure naphthalene added.	do	0.95	do	do	Do.
With 5 per cent filtered tar added.	do	0.45	do	do	Do.

[1] Toxic value based on 100 per cent pure salt.

TABLE IV.—*Toxicity of various preservatives to certain wood-destroying and other fungi*—Continued.

Toxic substance.	Organism.	Toxic point.	Culture medium.	Duration of test.	Investigator.
B.—ORGANIC COMPOUNDS—continued.					
(*b*) *Tars and creosotes*—Continued.					
Coal-tar creosote—Contd.		*Per cent.*			
With 10 per cent filtered tar added.	Penicillium	0.30	Agar	4 weeks	J. M. Weiss.
With 20 per cent filtered tar added.	...do	0.60	...do	...do	Do.
Coal tar (undistilled, sp. gr. 1.194 at 15.5° C.).	Molds	Between 1.5 and 2.	...do	...do	Do.
Coal-tar creosote:					
Fraction I (sp. gr. 0.934 at 60° C., 78.3 per cent distills below 215° C.).	Fomes annosus	0.30	...do	4 to 6 weeks.	Humphrey and Fleming.
Do	F. pinicola	0.225	...do	...do	Do.
Fraction II (sp. gr. 1.003 at 60° C., 9 per cent distills below 205° C., 95.9 per cent below 287° C.).	F. annosus	0.225	...do	5 to 9 weeks.	Do.
Do	F. pinicola	0.15	...do	4 to 5 weeks.	Do.
Fraction III (sp. gr. 1.045 at 60° C., 73.7 per cent distills below 295° C.).	F. annosus	0.325	...do	4 to 8 weeks.	Do.
Do	F. pinicola	0.125	...do	4 to 7 weeks.	Do.
Fraction IV (sp. gr. 1.088 at 60° C., 54.3 per cent distills between 285° and 320° C.).	F. annosus	3.3	...do	4 to 6 weeks.	Do.
Do	F. pinicola	0.125	...do	5 to 8 weeks.	Do.
Fraction V (10 per cent distills above 320° C., 36.6 per cent hard residue).	F. annosus	33	...do	4 to 6 weeks.	Do.
Do	F. pinicola	7.8	...do	5 to 8 weeks.	Do.
Fraction below 235° C.	Penicillium	0.35	...do	4 weeks	J. M. Weiss.
Fraction between 235°–272° C.	...do	0.25	...do	...do	Do.
Fraction above 272° C.	...do	Between 4 and 4.5.	...do	...do	Do.
Anthracene, pure	...do	Above 10	...do	...do	Do.
Naphthalene, pure	...do	Between 9 and 10.	...do	...do	Do.
Quinolin, pure	...do	0.10	...do	...do	Do.
Paraffin, pure	...do	Above 10	...do	...do	Do.
Water-gas tar distillate:					
Fraction between 170°–340° C.	Polystictus versicolor	0.40	...do		Dean and Downs.
Fraction between 170°–315° C. (sp. gr. 1.024 at 15.5° C.).	Penicillium	2	...do	4 weeks	J. M. Weiss.
Fraction between 210°–315° C. (sp. gr. 1.053 at 15.5° C.).	...do	Above 10	...do	...do	Do.
United Gas Improvement Co. oil (sp. gr. 1.058 at 60° C.).	Fomes annosus	Above 40	...do	4 to 8 weeks.	Humphrey and Fleming.
Do	F. pinicola	Above 40	...do	4 to 5 weeks.	Do.
Sp. gr. 0.995 at 60° C.	F. annosus	About 0.65	...do	5 to 8 weeks.	Do.
Wood creosote (softwood, sp. gr. 1.052 at 60° C.—about 8 per cent H_2O).	...do	0.65	...do	4 to 7 weeks.	Do.
Do	F. pinicola	0.20	...do	4 to 6 weeks.	Do.
Wood tar (hardwood, sp. gr. 1.195 at 60° C.).	F. annosus	1.25	...do	...do	Do.
Do	F. pinicola	0.75	...do	4 to 5 weeks.	Do.
Semiasphaltic petroleum (sp. gr. 0.973 at 15.5° C.: distills above 315° C.).	Penicillium	Above 10	...do	4 weeks	J. M. Weiss.

In conclusion, the writers wish to emphasize that any scale of toxicities derived from Petri-dish tests on the usual nutrient agar or

gelatin media, even when the tests are conducted under exactly similar conditions, do not necessarily represent the true relative toxic values of the different compounds, for the interaction between the toxic compounds, the nutrient substances contained in the media, and the plant protoplasm is variable and more or less specific for each combination.

Also, the reader should keep before him the fact that toxicity alone is not the sole criterion in judging the service value of a preservative, and a direct application of these data to that end would in many cases lead to very erroneous conclusions.

In many cases it is possible to overcome such unfavorable properties in a preservative as high solubility in water by placing the treated timber under conditions less exposed, and such timbers treated with soluble preservatives, such as sodium fluorid, zinc chlorid, and copper sulphate, should behave more or less according to the toxic ratios represented. The same should apply to oils of similar volatile and soluble properties placed under approximately similar service conditions.

Not all preservatives are adapted to the same uses, and in testing their service value these primary facts should be given full consideration. We have long been in the habit of taking as the standard test of the efficiency of a substance its ability to protect timber exposed to such extreme conditions as are railway ties, telephone poles, posts, exterior building timbers, etc. This standard is very often too severe, and for this reason preservatives should be grouped according to the conditions under which they are to be exposed.

SUMMARY.

A survey of the work of various investigators on the action of different toxic substances on the higher and lower forms of plant life discloses a marked difference in behavior. The action of toxic agents appears to be specific, being highly poisonous to certain organisms and only moderately so to others.

Very dilute concentrations ordinarily produce a stimulative effect.

Among the fungi, as a rule, the common molds are more resistant to poisons than the true wood-destroying fungi, and even among the latter group the different species show a great difference in susceptibility.

The chemical and physical composition of the media supporting the growth of the fungi determines, to a large extent, their development. The presence of certain kinds of insoluble matter or of such organic compounds as sugars and proteid materials, with which the toxic agents may possibly react, often introduces a considerable element of error when testing the toxic value of a substance by mixing it with nutrient agar or gelatin media.

Temperature is also an elemental factor in the growth of fungi, and there is an optimum for each organism, often lying within a very narrow range. The growth activities of fungi probably bear a close relation to the resistance offered toward toxic agents.

The toxic elements or radicals in a compound are often difficult to determine. In the case of heavy metallic salts, it is the metal ion; in the case of strong inorganic acids, the hydrogen ion is said to be the important element; in the fluorin compounds, fluorin is the determining agent; in the case of certain phenols, the introduction of halogen, alkyl, or nitro groups is said to increase toxicity. Even in the case of isomeric compounds the grouping of the radicals plays an important part.

The Petri-dish method of determining the toxicity of a substance offers a ready procedure which gives indicatory results in a short time. On account of certain sources of error, some inaccuracies must be admitted, although the methods employed by the writers obviate many of these.

The results of tests on 18 wood preservatives at the Forest-Products Laboratory, against two wood-destroying fungi, *Fomes annosus* Fr. and *F. pinicola* (Sw.) Fr., are given. The preservatives act in a considerably different manner on these two organisms, the former being, as a rule, far more resistant.

The tests show that for these two organisms the following quantities of preservative per cubic foot of culture medium used are sufficient to inhibit all growth:

FOR FOMES ANNOSUS.

	Pounds.
Coal-tar creosote, Fraction II	0.14
Sodium fluorid	.16
Cresol calcium	0.09– .18
Coal-tar creosote:	
Fraction I	.19
Fraction III	.20
Zinc chlorid	.31
Coal-tar creosote, grade C	.34
Water-gas tar distillate (sp. gr. 0.995)	.41
Wood creosote	.41
Hardwood tar	.78
Coal-tar creosote, Fraction IV	2.06
S. P. F. carbolineum	2.8
Avenarius carbolineum	3.27
Coal-tar creosote, Fraction V	20.59
Copperized oil	25
United Gas Improvement Co., 1.07 oil	Over 25
None-Such Special	Over 25
Sapwood antiseptic	Over 25

FOR FOMES PINICOLA.

	Pounds.
Coal-tar creosote:	
Fraction III	0.08
Fraction IV	.08
Fraction II	.09
Sodium fluorid	.09
Wood creosote	.13
Coal-tar creosote:	
Grade C	.14
Fraction I	.14
Avenarius carbolineum	.19
Zinc chlorid	.47
Hardwood tar	.47
Coal-tar creosote, Fraction V	4.87
Copperized oil	Over 25
United Gas Improvement Co., 1.07 oil	Over 25
None-Such Special	Over 25

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 228

Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.
May 22, 1915.

(PROFESSIONAL PAPER.)

EFFECT OF FREQUENT CUTTING ON THE WATER REQUIREMENT OF ALFALFA AND ITS BEARING ON PASTURAGE.[1]

By LYMAN J. BRIGGS, *Biophysicist in Charge of Biophysical Investigations*, and H. L. SHANTZ, *Physiologist, Office of Alkali and Drought Resistant Plant Investigations.*

INTRODUCTION.

The determination of a plant's efficiency in the use of water at different stages in its development is a problem of much interest, but one which involves serious experimental difficulties on account of the constantly changing environmental conditions and the consequent necessity of extensive multiplication of the series of experimental plants. The present experiments (Table I) were designed to determine (1) whether alfalfa in the early stages of growth following a cutting has a water requirement differing from the water requirement of the plant during the normal period of growth, and (2) to what extent frequent cutting or grazing during the hottest part of the year modifies the seasonal water requirement.

METHOD.

Two standard sets of selected Grimm alfalfa,[2] each consisting of six pots of plants, were employed in these experiments. The plants were treated in the usual way [3] up to the time of the first cutting, on July 26, at which time care was taken to leave the basal shoots, so as to insure the uninterrupted growth of the plants. Following this date, the growth on the pots of series B was cut back weekly in a manner somewhat resembling pasturage (fig. 1), all of the material thus removed from each pot being preserved separately. The growth of the plants in series A was allowed to proceed without interruption

[1] The experiments reported in this bulletin were conducted at Akron, Colo., in 1912. The methods employed were essentially the same as those described in Bulletin 284 of the Bureau of Plant Industry, entitled "The Water Requirement of Plants. I.—Investigations in the Great Plains in 1910 and 1911." Sealed pots were used to prevent evaporation from the soil and the entrance of rainfall. The writers are indebted to A. M. Peter, R. D. Rands, H. Martin, and G. Crawford for assistance given at Akron in 1912.

[2] The strains were selected by A. C. Dillman, of the Office of Alkali and Drought Resistant Plant Investigations.

[3] See Bulletin 284 of the Bureau of Plant Industry, previously mentioned, for details of these experiments. Series B was, however, started 10 days later than the check series (A), owing to the necessity of replanting.

until the time of the second cutting (fig. 2). Both sets were then allowed to grow uninterruptedly until the third and final cutting was

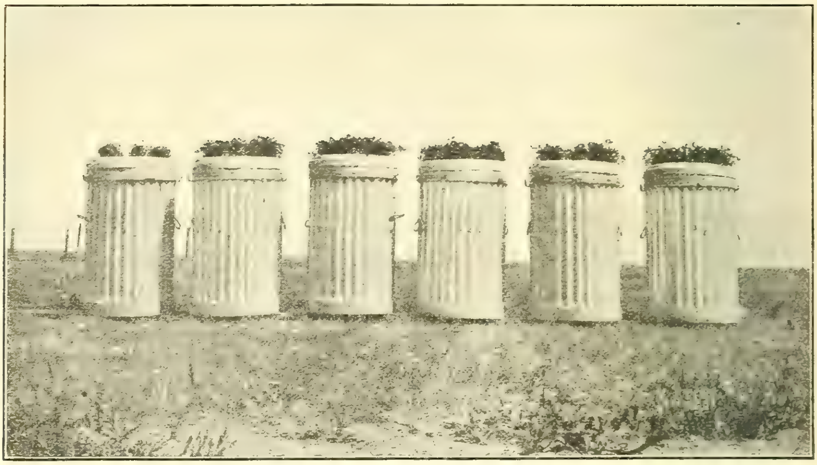

FIG. 1.—Alfalfa (series B, pots 145 to 150), photographed just before cropping, September 7, 1912.

made. The data for the individual pots will be found in Table I, where the results are also summarized.

RESULTS.

The water requirement of the two series during the first period (i. e., up to the time of the first cutting) was practically the same.

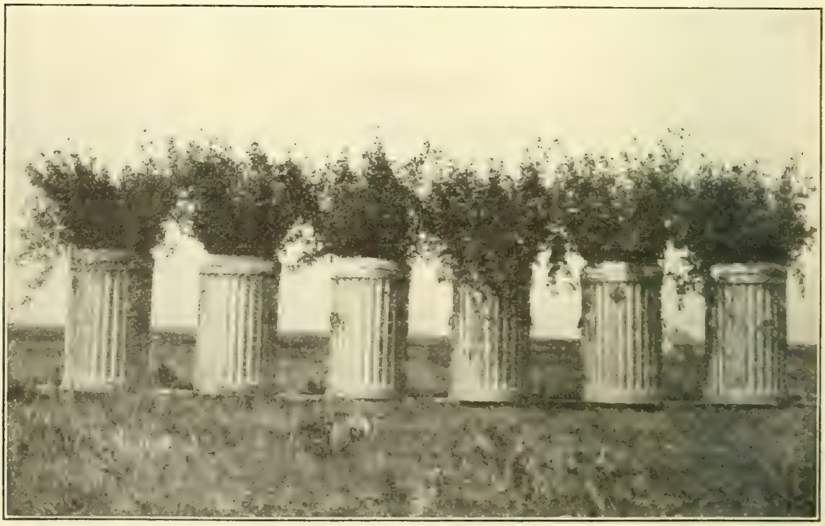

FIG. 2.—Alfalfa (series A, pots 133 to 138), photographed just before the second cropping, September 6, 1912.

The mean ratio of the six pots of series A (check) was 600 ± 17 and of series B 615 ± 6. The difference is less than the probable error.

TABLE I.—*Dry-matter production and water consumption of alfalfa as affected by frequent cutting, at Akron, Colo., in 1912.*

Period of growth.	Series A: Grimm alfalfa, A.D.I., E-23-20-52 (*Medicago sativa*). Pot No.	Dry matter.	Water absorbed.	Water requirement based on dry matter.	Period of growth.	Series B: Grimm alfalfa, A.D.I., E-23-20-52 (*Medicago sativa*). Pot No.	Dry matter.	Water absorbed.	Water requirement based on dry matter.
		Grams.	*Kilos.*				*Grams.*	*Kilos.*	
May 24 to July 26	133	131.6	89.6	680	June 3 to July 26	145	53.3	33.1	621
	134	121.4	73.9	609		146	89.3	54.7	612
	135	141.0	82.4	584		147	59.8	37.5	627
	136	140.6	72.5	516		148	78.3	50.5	645
	137	141.4	79.8	564		149	100.6	60.5	602
	138	118.0	76.6	649		150	91.0	53.0	582
Average				600±17	Average				615±6
July 26 to Sept. 6	133	131.7	118.8	902	July 26 to Sept. 7. Cropped Aug. 3, 10, 17, 24, 31, and Sept. 7.	145	20.6	22.5	1,092
	134	110.0	93.0	845		146	25.7	25.1	974
	135	138.6	112.4	810		147	26.8	25.2	941
	136	133.3	115.8	870		148	32.3	28.4	880
	137	135.2	108.1	800		149	23.7	25.7	1,088
	138	120.2	107.4	893		150	30.3	26.4	872
Average				853±13	Average				975±23
Sept. 6 to Nov. 4	133	73.7	35.4	479	Sept. 7 to Nov. 4	145	34.7	15.6	450
	134	64.7	28.1	434		146	37.1	16.5	445
	135	80.7	32.4	401		147	38.8	19.8	510
	136	82.0	32.0	390		148	35.0	16.4	467
	137	83.8	36.1	431		149	39.3	20.1	571
	138	79.5	31.1	391		150	38.3	16.4	428
Average				421±10	Average				479±16
Combined cuttings, May 24 to Nov. 4.	133	337.0	243.8	724	Combined cuttings, June 3 to Nov. 4.	145	108.6	71.2	655
	134	296.1	195.0	658		146	152.1	96.3	633
	135	360.3	227.2	632		147	125.4	82.5	658
	136	355.9	220.3	620		148	145.6	95.3	654
	137	360.4	224.4	623		149	163.6	106.3	650
	138	317.7	215.1	678		150	159.6	95.8	600
Average				656±11	Average				642±6

SUMMARY.

Period of growth.	Total dry matter produced (6 pots).		Total water absorbed (6 pots).		Water requirement.	
	Series A.	Series B.	Series A.	Series B.	Series A.	Series B.
	Grams.	*Grams.*	*Kilos.*	*Kilos.*		
May 24 to July 26[1]	794.0	472.3	474.8	289.3	600±17	615±6
July 26 to Sept. 6	769.0	159.4	655.5	153.3	853±13	975±23
Sept. 6 to Nov. 4	464.4	223.2	195.1	104.8	421±10	479±16
Combined	2,027.4	854.9	1,325.8	547.4	656±11	642±6

[1] Series B was replanted June 3.

During the second period the water requirement of the check series was 853 ± 13, while the series which was cut weekly during this period gave a water requirement of 975 ± 23, an increase of 14 ± 4 per cent. It thus appears that alfalfa is slightly less efficient in the use of water when subjected to weekly cuttings.

During the third period, when both sets were again treated alike, the water requirement of the check series (A) was 421 ± 10 and that of series B 479 ± 16. The B series thus shows during the third period also a slight increase (14 ± 4 per cent) in water requirement compared with series A, which may be the result of the weakening of the

plants during the second period through the forced reduction in the leaf and stem area of the plant. This would tend to prevent the normal development of the root system, which in turn would increase the water requirement during the third period, since a relatively greater proportion of food material would be diverted to the roots.

When the water requirement is based on the total dry matter produced during the season (May 24 to November 4) without reference to the time at which the growth occurred, series B is practically as efficient as the check series. The respective ratios were 642 ± 6 and 656 ± 11, the difference, 14 ± 13, being without significance. This is of interest in view of the fact that the water requirement of each of the three crops is higher in series B than in the check series. The explanation of this seeming anomaly is to be found in the relative yields during the second (midsummer) period, during which time series B produced only 18 per cent of its total dry matter, while the check series produced 38 per cent.

The amount of dry matter produced under frequent cutting is also of interest. The check series produced practically the same amount of dry matter during the second period as during the first. Series B produced only 30 per cent as much during the second period, the small plants being unable to elaborate plant material as rapidly as the larger plants of series A. Series B was also maintained during the midsummer period with an actual expenditure of only one-third the water required by the check series. This forced economy in the use of water through frequent cutting seems not to be without effect on subsequent production. Series B produced only 48 per cent as much dry matter during the third period as the check series, while during the first period, notwithstanding the shorter period of growth, series B produced 60 per cent as much dry matter as the check series.

BEARING OF RESULTS ON THE MANAGEMENT OF ALFALFA LANDS.

The results here recorded indicate that the total consumption of water can be controlled to a considerable extent by pasturage or frequent clipping without serious injury to alfalfa plants. This affords a means of limiting the growth of the crop so that its demand for water will not exceed the available moisture supply. With a limited amount of stored moisture it is evident that the greatest production can be obtained by allowing the crop to grow when the water requirement is the lowest, i. e., in the spring or fall, and by keeping the leaf surface at a minimum during the summer through clipping or pasturage. Numerous field observations by the writers have shown the efficacy of reducing the size of the aerial portion of a plant as a means of moisture conservation during periods of drought.

Although frequent cutting or clipping is not practicable under field conditions, the same result can be attained by grazing. Whenever

the moisture supply falls short of the amount necessary to produce normal crops throughout the season, summer grazing appears to afford a simple and practical means of obtaining a return from alfalfa commensurate with the available moisture and at the same time reduces the danger of drought injury.

In the pot experiments already described, weekly cutting reduced the total amount of dry matter produced to one-third the normal crop. This would indicate that when the moisture supply is adequate for continuous crop production throughout the season, close pasturage or clipping would result in a marked reduction in the amount of alfalfa produced. Consequently, where grazing is practiced greater production can be secured by intermittent grazing; that is, by employing several fields which are pastured in rotation.

SUMMER PASTURAGE OF ALFALFA EXTENSIVELY PRACTICED IN AUSTRALIA.

Since the experimental work referred to above was completed, the writers have learned that a practice similar to that suggested has been gradually developed in Australia as giving the best return in the management of Australian alfalfa land. The practice is to grow a hay crop in the early spring and to pasture the alfalfa during the remainder of the year. Aside from the hay obtained, alfalfa is very valuable in Australia for grazing purposes, because it responds to summer rainfall, while the native grasses, being annuals, afford no late pasturage. On a large ranch or "station" near Wagga Wagga, New South Wales, one of the writers recently saw 1,000 acres of Peruvian alfalfa that is being handled under this combined system of hay and pasturage. The alfalfa at this station carries three sheep per acre during the summer, autumn, and winter months. About the first of September (early spring) the sheep are taken off. The alfalfa makes a luxuriant growth during the cool spring months, and a crop of from 1,500 to 2,000 pounds per acre of cured hay is obtained. The hay is produced when the weather is cool and the transpiration rate low—in other words, when the crop is making the most efficient use of the water supply. The normal rainfall in this region is about 21 inches and is quite uniformly distributed, each month having more than 1 inch of rainfall and only two months (June and October, corresponding in season to our December and April, respectively) more than 2 inches.

At another station an alfalfa field of 120 acres was seen, which is being treated in the same way. The sheep are taken off the middle of August, and the alfalfa is usually cut the last week in October. The single cutting averages about 1 ton to the acre. The rainfall is about 22 inches a year.

This combined system of hay and pasturage has found much favor in New South Wales and is carried out in a rolling-plains country on loam or sandy-loam soils where there is no possibility of subirrigation.

PUBLICATIONS OF THE DEPARTMENT OF AGRICULTURE RELATING TO THE SUBJECT MATTER OF THIS BULLETIN.

Other publications of the Department of Agriculture in the same field as this bulletin are obtainable from the Superintendent of Documents, Government Printing Office, at the prices specified.

The Water Requirements of Plants. I.—Investigations in the Great Plains in 1910 and 1911. By Lyman J. Briggs and H. L. Shantz. U. S. Department of Agriculture, Bureau of Plant Industry Bulletin 284, 49 pp. and 11 pls., 1913. Price, 15 cents.

The Water Requirement of Plants. II.—A Review of the Literature. By Lyman J. Briggs and H. L. Shantz. U. S. Department of Agriculture, Bureau of Plant Industry Bulletin 285, 96 pp., 1913. Price, 10 cents.

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WASHINGTON : GOVERNMENT PRINTING OFFICE : 1915

UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 229

Contribution from the Forest Service
HENRY S. GRAVES, Forester

Washington, D. C. ▲ July 28, 1915.

THE NAVAL STORES INDUSTRY.

By A. W. Schorger, *Chemist in Forest Products*, and H. S. Betts, *Engineer in Forest Products, Forest Products Laboratory*.[1]

CONTENTS.

NEED FOR IMPROVED METHODS.

The business of producing naval stores is unique among American industries in one particular. Until recently there has been practically no change in methods since its first establishment. Those in vogue before the War of the Revolution are mainly the ones in force to-day. Very recently the cup method of turpentining the trees has been taken up, but the wasteful box method is still largely used. Outside of this the average operator has been content to follow the methods of his predecessors, both in collecting the gum and in distilling it. With conditions in the industry as they are at present, when the supply of longleaf pine in North Carolina, South Carolina, and Georgia suitable for turpentining is very nearly exhausted, and when the cost of operation everywhere is high in proportion to the returns,

[1] Maintained by the Forest Service in cooperation with the University of Wisconsin, Madison, Wis.

Note.—This bulletin is of interest to the producers and users of naval stores.

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the need for improved methods, for attention to detail, is imperative if the industry is to have a future. Ways of collecting the gum which will give the maximum amount for the longest time with the least injury to the tree and methods of distillation which will insure turpentine and rosin of the best grade are things which every operator might well make the subject of study. Nowhere more than in the naval stores industry will close attention to detail coincide with successful operation.

This bulletin reviews the present status of the naval stores industry and the progress which has been made in improving the methods of collecting and distilling the gum.[1] Information is also presented on the supply of timber at present available for turpentine operations.

The publications listed in the latter part of this bulletin have been drawn upon in its preparation, and acknowledgement is made to the several authors.

HISTORY OF THE INDUSTRY IN THE UNITED STATES.

The earliest mention of turpentine and rosin seems to exist in a manuscript dated 1610, preserved in the Public Record Office, London, and entitled "Instructions for suche things as are to be sente from Virginia."[2]

"Hard pitche," "Tarre," "Turpentine," and "Rozen" are also mentioned in the "Booke of the Commodities of Virginia," issued presumably about the same time.

Pitch and tar were the chief products of the industry up to the middle of the eighteenth century. Their extensive use in the construction and maintenance of sailing vessels caused them to be called "naval stores," a term now applied to the turpentine and rosin industry, which has supplanted the production of tar and pitch.

The manufacture of turpentine and rosin in North Carolina was described by Schoepf in 1783–84. Pitch and tar, however, had been staple products since 1700. Norfolk was the great shipping point for Virginia and northeastern North Carolina.

The method of boxing the trees for collecting the crude gum was the same as that employed to-day, but the names of some of the operations have changed, such as "cornering" in place of "notching," and "virgin dip" in place of "pure dippings."

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[1] The Bureau of Chemistry of the Department of Agriculture is now investigating problems connected with the distillation of turpentine, and has offered helpful suggestions in the case of this bulletin.

[2] Among the instructions is the following: "Pyne trees, or ffirre trees are to be wounded wthin a yarde of the grounde, or boare a hoal wth an agar the thirde pte into the tree, and lett yt runne into anye thinge that maye receyue the same, and that wch yssues owte wilbe Turpentyne worthe 18£ Tonne. When the tree beginneth to runne softelye yt is to be stopped vp agayne for preserveinge the tree."

"Pitche and tarre hath bene made there and we doubte not but wilbe agayne, and some sente for a sample, your owne tournes beinge firste served."

Previous to 1800 very little of the crude turpentine was distilled at the point of production. Tapping operations were conducted, so far as possible, along navigable streams and inlets. The crude turpentine was then shipped to Wilmington, Philadelphia, and New York, and there reshipped to England for distillation. Up to the year 1820 the production of turpentine and rosin was quite unimportant and limited to the demands of domestic industries. The rosin manufactured was worth very little, the price dropping to 25 cents a barrel and even lower, so that it could no longer be handled at a profit.

Copper stills were introduced in 1834, and greatly improved manufacturing conditions. Previously the distillations had been conducted in crude cast-iron retorts that gave very poor results, both as to quantity and quality of the products.

Up to the year 1838 the industry had not advanced south of the Cape Fear River, the belief being that the pines farther south would not flow sufficiently. This error was soon discovered through a few experiments, and the practically untouched belt of longleaf pine forest extending from the Carolinas to Texas was gradually invaded.

Increasing demands for turpentine in the varnish and paint industries; its utilization as a solvent for rubber and as an illuminant when mixed with alcohol, and the passage of the British free trade law of 1846 combined to stimulate production. In proportion as the demand for turpentine increased a greater amount of rosin was manufactured than could be utilized in the arts, and so went to waste.

The Civil War had a depressing effect upon the industry. Only about two-thirds of the number of establishments reported for 1860 were in operation in 1870.

STATISTICS OF PRODUCTION.

Except for the period between 1860 and 1870, the naval stores industry has had a steady growth, so far as the value of its products is concerned. The market prices are subject to great variation,[1] not only according to supply and demand, but also through manipulation on the exchange. Figure 1 shows the high and low prices by years since 1901 for turpentine and for two grades of rosin.

During the last five years the average annual production, in round numbers, has been 31,800,000 gallons of turpentine and 3,700,000 barrels of rosin. Over half of the products are exported, this country largely supplying the world. France, Austria, Spain, Portugal, India, Greece, and other countries also produce naval stores, but the amounts are relatively small, as may be seen from Tables 1 to 4, which show the exports and imports of turpentine and rosin by various countries from 1901 to 1912.

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[1] During the season 1909–10 the lowest price of turpentine per gallon was 35½ cents, while during 1910–11 the high-water mark of $1.07 was reached. The lowest quotation ever posted by the Savannah Board of Trade was on Sept. 4, 1896, when turpentine brought but 22 cents a gallon.

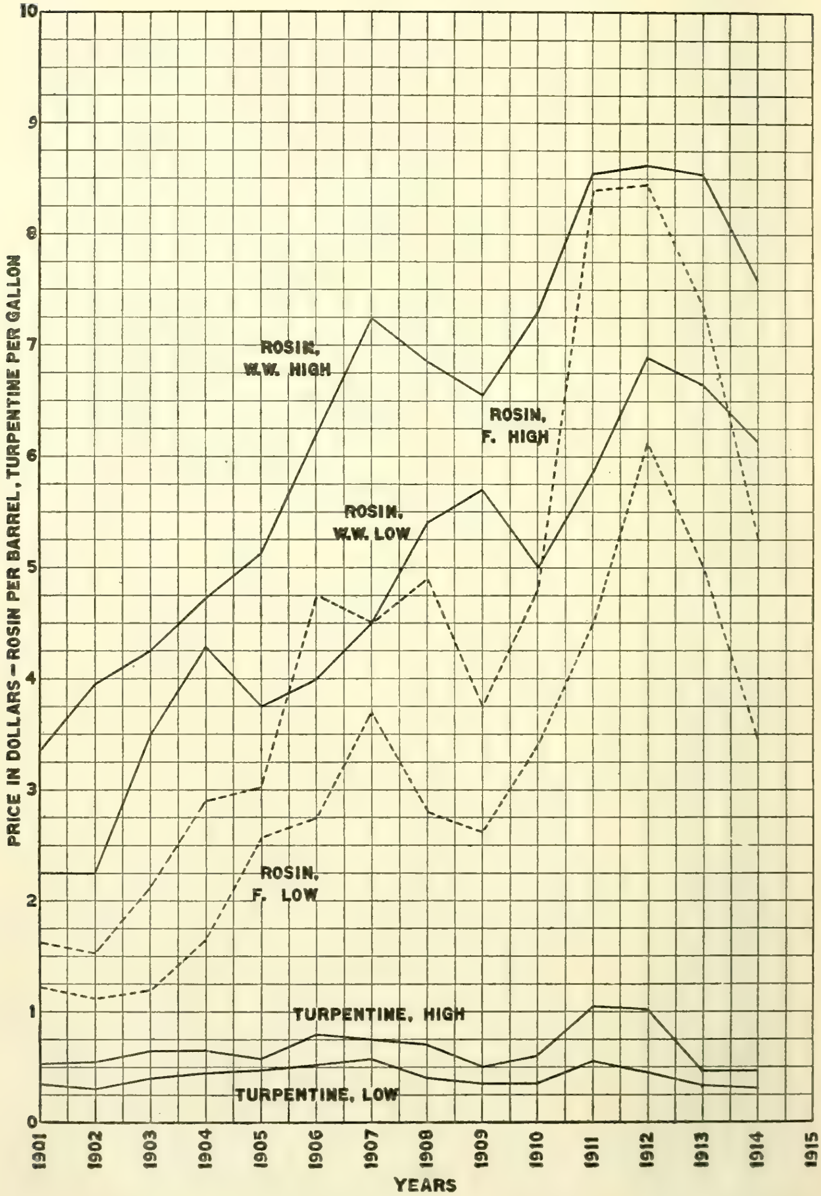

FIG. 1.—High and low prices by years since 1901 for turpentine and two grades of rosin.

TABLE 1.—*Exports of turpentine (gallons) by various countries, 1901–1910.*

Country.	1901	1902	1903	1904	1905
France	833,918	925,784	1,975,943	1,459,282	3,179,073
Germany [1]	565,174	502,434	612,052	569,644	520,745
Netherlands	941,518	1,288,866	988,049	876,921	972,704
Russia	1,483,439	1,516,096	1,887,430	2,163,759	2,504,423
Spain	[2] 1,089,669	[2] 1,089,669	[2] 1,089,669	[2] 1,089,669	[2] 1,089,669
United States	20,627,633	18,620,317	15,651,937	16,426,756	15,614,323
Other countries	60,000	60,000	72,000	113,000	90,000
Total	25,601,351	24,003,351	22,277,080	22,669,031	23,970,937

Country.	1906	1907	1908	1909	1910
France	3,367,337	2,538,689	2,397,686	2,400,228	2,851,038
Germany [1]	460,731	349,552	433,235	380,385	429,499
Netherlands	1,400,631	165,771	1,851,918	2,068,870	1,812,021
Russia	2,456,844	2,705,255	1,773,655	1,833,377	2,473,311
Spain	[2] 1,089,669	907,429	1,131,140	1,150,493	1,169,615
United States	16,182,500	17,176,843	19,433,181	16,061,783	14,252,321
Other countries	106,000	95,000	226,000	444,000	576,000
Total	25,063,712	25,448,539	27,246,815	24,339,136	23,563,805

[1] Not including free ports prior to Mar. 1, 1906. [2] Average 1907–1910.

TABLE 2.—*Imports of turpentine (gallons) by various countries, 1901–1910.*

Country.	1901	1902	1903	1904	1905
Austria-Hungary	1,762,578	1,821,949	1,739,705	2,071,834	2,021,465
Canada	923,370	908,151	890,135	910,443	948,100
Germany	8,435,688	8,077,409	8,300,166	8,438,872	8,539,824
Italy	658,410	663,187	771,457	816,621	687,284
Netherlands	1,895,548	3,245,583	2,729,788	2,220,134	2,248,032
United Kingdom	9,701,051	7,942,324	8,012,184	7,907,419	7,693,933
Other countries	2,218,199	1,655,645	1,931,217	2,453,412	2,199,739
Total	25,594,844	24,314,248	24,374,652	24,818,735	24,338,377

Country.	1906	1907	1908	1909	1910
Austria-Hungary	2,218,072	2,291,131	2,409,689	2,439,635	2,502,527
Canada	1,011,283	1,028,936	1,081,180	1,141,238	1,044,734
Germany	9,966,690	8,986,011	10,088,770	9,764,051	8,659,883
Italy	948,162	921,278	1,020,117	824,643	855,538
Netherlands	2,711,769	3,035,996	3,932,317	2,785,377	2,696,243
United Kingdom	7,673,758	7,515,293	8,656,464	6,522,833	7,041,316
Other countries	3,174,227	3,172,429	2,947,196	2,478,389	2,848,791
Total	27,703,961	26,951,074	30,135,733	25,956,166	25,649,032

TABLE 3.—*Exports of rosin (barrels) by various countries, 1901–1910.*

Country.	1901	1902	1903	1904	1905
Austria-Hungary	12,933	12,066	11,884	12,955	12,044
Germany	150,918	120,558	159,115	162,918	165,606
Netherlands	233,833	267,343	225,136	299,794	209,085
Russia	140,289	135,978	125,565	147,971	174,273
Spain	10,000	17,143	23,929	32,143	56,429
United States	2,691,523	2,629,519	2,563,977	2,501,521	2,258,126
Other countries	1,168	2,095	5,820	9,765	20,266
Total	3,240,664	3,184,702	3,115,426	3,167,067	2,895,829

Country.	1906	1907	1908	1909	1910
Austria-Hungary	11,266	10,784	9,399	8,188	7,255
Germany	164,602	196,495	217,706	171,497	198,865
Netherlands	284,104	273,832	309,885	202,249	199,335
Russia	147,161	174,607	139,826	90,410	137,661
Spain	51,786	61,967	60,394	53,183	80,602
United States	2,481,269	2,636,149	2,601,181	1,984,525	2,269,339
Other countries	20,045	22,455	18,340	20,114	43,294
Total	3,160,233	3,376,289	3,356,731	2,530,166	2,936,351

TABLE 4.—*Imports of rosin (barrels) by various countries, 1901–1910.*

Country.	1901	1902	1903	1904	1905
Austria-Hungary	284,128	208,749	257,576	231,515	223,149
Canada	140,639	28,001	57,033	93,118	67,525
Germany [1]	839,724	705,489	844,585	834,069	743,905
Russia	237,030	234,733	241,735	234,261	213,489
United Kingdom	692,980	721,487	655,742	712,778	632,181
Other countries	777,341	870,925	770,066	935,580	842,835
Total	2,971,842	2,769,384	2,826,737	3,041,322	2,723,084

Country.	1906	1907	1908	1909	1910
Austria-Hungary	261,980	265,415	294,012	250,822	253,425
Canada	68,454	78,058	60,729	82,026	85,438
Germany [1]	840,351	884,393	1,022,197	774,308	857,970
Russia	216,361	242,655	269,738	201,176	223,629
United Kingdom	624,988	634,051	613,209	530,192	568,914
Other countries	859,326	953,244	1,031,975	826,077	901,688
Total	2,871,460	3,057,816	3,291,860	2,664,601	2,891,064

[1] Not including free ports prior to Mar. 1, 1906.

Tables 5 and 6 show the growth and present magnitude of the turpentine and rosin industry in the United States and the large amount of capital involved in producing and exporting naval stores. It would seem from Table 6 that the production of turpentine and rosin in this country has reached its maximum, and this conclusion is further borne out by a survey of the stumpage supply still available for naval stores operations (p. 41). Table 7 shows the exports of naval stores by States.

TABLE 5.—*Number of establishments and quantity and value of turpentine and rosin produced—United States.*

[Figures taken from reports of the Bureau of the Census.]

Year.	Number of establishments.	Turpentine.		Rosin.		Combined value of turpentine and rosin.
		Gallons.	Value.	Barrels.	Value.	
[1] 1913		32,000,000		3,815,000		
[1] 1912		34,000,000		4,000,000		
[1] 1911		31,900,000		3,800,000		
1910		27,750,000	$17,680,000	3,651,000	$18,255,000	$35,935,000
1909	1,585	28,941,000	12,654,000	3,258,000	12,577,000	25,231,000
1908	1,696	36,589,000	14,112,000	4,288,000	17,795,000	31,907,000
1907	1,629	34,181,000	18,283,000	3,999,000	17,317,000	35,600,000
1904	1,287	30,687,000	15,170,000	3,508,000	8,726,000	23,896,000
1900	1,503	38,488,000	14,960,000	2,563,000	5,129,000	20,090,000
1890	670					[2] 8,077,000
1880	508					[2] 5,877,000
1870	227					[2] 3,585,000
1860	625					[2] 6,468,000
1850	856					[2] 2,856,000
1810		122,900	176,650	[3] 2,000		

[1] According to Naval Stores Review of Apr. 4, 1914.
[2] Combined value of all naval stores.
[3] Includes pitch.

TABLE 6.—*Quantity and value of spirits of turpentine and rosin exported, 1860–1913.*

[Figures from the Bureau of the Census.]

Year (ending June 30).	Turpentine		Rosin.	
	Gallons.	Value.	Barrels.	Value.
1913	21,039,597	$8,794,656	2,806,046	$17,359,145
1912	19,599,241	10,069,135	2,474,460	16,462,850
1911	14,817,751	10,768,202	2,189,607	14,067,335
1910	15,587,737	8,780,236	2 144,318	9,753,488
1909	17,502,028	7,018,058	2,170,177	8,004,838
1908	19,532,583	10,146,151	2,712,732	11,395,126
1905	15,894,813	8,902,101	2,310,275	7,069,084
1903	16,378,787	8,014,322	2,396,498	4,817,205
1900	18,090,582	8,554,922	2,369,118	3,796,367
1890	11,248,920	4,590,931	[1] 1,601 377	[1] 2 762,373
1880	7,091,200	2,132,154	[1] 1,040,345	[1] 2,368,180
1870	3,246,697	1,357,302	[1] 583,316	[1] 1,776,625
1860	4,072,023	1,916,289	[1] 770,652	[1] 1,818,238

[1] Turpentine included with rosin.

TABLE 7.—*Exports of spirits of turpentine and turpentine and rosin by decimal years, 1860–1900.*

[Figures from Twelfth Census of the United States, No. 126.]

State.	1900		1890		1880	
	Spirits of turpentine.	Turpentine, rosin, and pitch.	Spirits of turpentine.	Turpentine, rosin, and pitch.	Spirits of turpentine.	Turpentine and rosin.
	Gallons.	*Barrels.*	*Gallons.*	*Barrels.*	*Gallons.*	*Barrels.*
Alabama	153,018	58,646	210			22,373
Alaska		7				
California	45	535		25	6,055	125
Delaware						1,375
Florida	795,267	243,452	1,742	940	25,728	12,215
Georgia	14,623,328	1,408,928	7,251,929	841,217	570,549	91,909
Louisiana	212,031	47,890	599	1,128	276	5,089
Maine	34,103	831	4,062	79	90	528
Maryland	111	174,416	3,002	50,928	754	7,623
Massachusetts	2,044	18,359	29,418	7,038	50,915	3,612
Michigan	307,716	3,879	5,434	1,939	7,639	103
Minnesota		5	7,053	5	362	17
Mississippi		2				10
Montana and Idaho	11					
New York	1,630,164	252,801	894,287	267,801	1,105,100	227,746
North Carolina	53,974	139,767	1,751,270	304,100	3,630,009	497,456
North and South Dakota	39,649	1,774				
Ohio	40					
Oregon			650			
Pennsylvania	121	144	500	1,201	1,443	7,974
Rhode Island						
South Carolina		21,248	1,293,389	140,399	1,691,447	158,563
Texas	659	126	1,515	412	762	42
Vermont	235,776	15,631			41	
Virginia				2,491	30	3,585
Washington	2,525	923	3,860			
Wisconsin				1		
Total	18,090,582	2,389,364	11,248,920	1,619,704	7,091,200	1,040,345

TABLE 7.—*Exports of spirits of turpentine and turpentine and rosin by decimal years, 1860–1900*—Continued.

State.	1870		1860	
	Spirits of turpentine.	Turpentine and rosin.	Spirits of turpentine.	Turpentine and rosin.
	Gallons.	*Barrels.*	*Gallons.*	*Barrels.*
Alabama	462	885		500
California	1,965	76	1,280	2
Connecticut			640	10
Florida	90	518		
Georgia		519	137	134
Louisiana	7,558	8,423	11,197	18,909
Maine		41		160
Maryland	6,104	30,626	38,080	20,268
Massachusetts	52,511	11,435	123,163	16,605
Michigan		32		
Minnesota		1		
New York	796,824	464,538	2,816,768	562,253
North Carolina	2,042,756	33,212	736,948	77,851
Ohio		1		
Pennsylvania	544	3,063	25,511	19,845
Rhode Island			200	534
South Carolina	337,530	25,279	315,099	50,753
Texas	273	318		
Vermont		2		80
Virginia	80	4,347	3,000	2,748
Total	3,246,697	583,316	4,072,023	770,652

NOTE.—The exports of turpentine and rosin from a State bear no relation to the amounts actually produced within the State, but to the possession of shipping centers for the naval stores trade.

COMMERCIAL UTILIZATION OF PRODUCTS.

TURPENTINE.

Paints and varnishes.—The greater portion of the turpentine produced finds its way into paints and varnishes. The three main classes of varnishes are spirit varnishes, linseed-oil varnishes, and turpentine varnishes. The turpentine varnishes are made by dissolving resins, such as amber, copal, etc., in hot turpentine and are tough and flexible. Linseed-oil varnishes are often diluted with turpentine.

Turpentine is used in paints and varnishes chiefly as a thinner, of which the properties demanded are solvent action, oxidizing power, penetration, and proper evaporation.

Print goods.—Turpentine finds an important use in the manufacture of cotton and woolen print goods in preventing "bleeding," or running together of colors, where several colors are printed at the same time. It also prevents the color from penetrating the fabric, which is particularly important in the case of woolen goods if unevenness of the material is to be avoided.

Camphor.—Many attempts have been made to produce camphor from turpentine on a commercial scale, but so far none has been entirely successful. However, terpineol, terpin hydrate, and similar bodies are manufactured from turpentine in considerable quantities.

Rubber industry.—Turpentine is important as a solvent for rubber, caoutchouc, and similar substances.

ROSIN.

Rosin is employed extensively in the manufacture of soap, paper, oilcloth, linoleum, sealing wax, fly paper, printing inks, roofing materials, brewer's pitch, electric wiring, lubricating compounds, medicinal preparations, etc.

Rosin soap.—Rosin has the property of combining with alkalies, such as caustic soda and potash, to form "soaps" which are readily soluble in water. Their color is yellowish or yellowish-brown, depending on the color of the rosin used. At ordinary temperatures rosin soaps have the consistency of butter, and on account of their relative cheapness, are usually added to the hard soaps made from tallow. In themselves, however, rosin soaps possess valuable properties, and their addition to tallow or other hard soaps can not always be considered an adulteration.

Resin driers.—The metallic salts of the resin acids are known as driers. They are made by adding a solution of the salt of a metal such as manganese to a solution of "rosin soap" when the insoluble manganese resinate precipitates; or the rosin is fused with the metallic oxide. These metallic resinates, known as "Japan driers," cause the oxidation or "drying" of oil paints and varnishes and are extensively used for this purpose. The lead and manganese resinates are used most frequently.

The various enamels used in ceramics consist of resinates of the various heavy metals. The resinates are dissolved in turpentine and the resulting solution painted on the earthenware, after which the vessels are "fired."

Rosin size.—One of the most important uses of rosin is as a "size" or coating for writing or printing papers, which must take ink. A rosin soap, containing about 3 pounds of rosin to 1 of soda, is added to the pulp in the hollander, and after that a solution of alum. The latter decomposes the rosin soap, and the result is a precipitate of free rosin and some alumina which becomes entangled in the fibers of the paper. When the paper is passed over hot calendar rolls in finishing, the rosin fuses to a smooth, varnish-like layer on the surface.

Brewers' pitch.—Barrels intended to hold beer or other fermented beverages are coated with brewers' pitch, which renders the barrels easy to clean and improves the taste of the beer. The pitch is made of pure rosin, with the addition of a certain amount of turpentine or refined rosin oil to prevent brittleness. Some manufacturers make the pitch supple by adding rosin soap.

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Products of the distillation of rosin.—When rosin is heated at temperatures above its melting point it decomposes[1] into gases and oils.

The lightest of these oils, rosin spirit or pinoline, is used as an illuminant, and also as a solvent, especially as a substitute for turpentine. The heavier rosin oils are used in the manufacture of printing inks and lubricants. Wagon grease is often made by boiling rosin oil with lime.

The distillation of rosin is carried out on a large scale in Germany and France, the darker grades of rosin imported from America being used for this purpose. Comparatively little is distilled in the United States.

Lampblack.—Rosin oil can be used for the manufacture of lampblack which, from the standpoint of color and minuteness of division, is of the highest quality. The finest grades are used in the manufacture of india ink, in lithography, and in artistic printing with copper plates.

FORMATION AND FLOW OF RESIN IN THE LIVING TREE.

Resin suitable for the production of naval stores is found only in in coniferous trees. Moreover, only pines yield resin abundantly, and of these only two species, longleaf pine (*Pinus palustris*) and, to a small extent, slash pine[2] (*Pinus heterophylla*) are tapped in the United States.

No universally accepted theory dealing with the formation of resin has as yet been advanced. It is generally conceded, however, that resin is formed as a by-product during the transformation of food materials, such as starch, into woody tissue. The resin is stored in two systems of elongated passages or resin ducts. In one system the ducts are parallel to the pith of the tree; in the other they lie horizontally in radial planes. The ducts form in the growing tissue or cambium layer just beneath the bark, the two systems intersecting to form a continuous network of resin passages.

When the cambium layer is cut the growth of tissue near the wound is stimulated, and the number of resin ducts, and consequently the amount of resin formed, is considerably increased. The area in which additional or secondary resin ducts are formed apparently extends from 2 to 3 inches above and to a lesser distance below the wound.

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[1] The products resulting from distillation and their percentages are as follows:

Losses (rosin adhering to walls of still) per cent..	1.0	Light oil (turbulent) per cent..	5.0
Gases evolved do....	9.0	Light oil, hearts do....	58.0
Acid water do....	3.5	Blue oil and red oil do....	16.0
Rosin spirit or pinoline do....	3.5	Residue, coke do....	4.0

[2] Slash pine is of comparatively infrequent occurrence, but is tapped wherever found on areas being turpentined.

The additional ducts require from 2 to 4 weeks for their formation full of resin.

If a new cut is made just above the old one, after the additional ducts have had a chance to form, the flow will show a large increase over that obtained from the original wound, due to the additional ducts.

Depth of cut.—Since the additional ducts form only in the cambium layer, and since they yield by far the greater part of the resin, cutting deeper than this layer induces but little additional flow. In commercial operations the depth of the cuts or "streaks" runs from one-half to one inch. Such streaks are, of course, much deeper than necessary, and to just that extent tend to reduce the vitality of the tree and, in consequence, its ability to give a sustained flow. Tests have shown that a greater average flow over a four-year period can be obtained from trees with streaks 0.4 inch deep than from trees with streaks 0.7 inch deep. In any case, shallow streaks give fully as large a flow of resin as deep ones, when the period of tapping extends over two years or more. The tools used at present, however, make it difficult to cut shallow streaks, while the custom of deep chipping is pretty firmly established through long usage.

Height of chip.—When a new "streak" is made the flow of gum is at first comparatively rapid, but gradually decreases until at the end of a week it has practically ceased. The diminution of flow is presumably caused by the gradual hardening of the resin in the exposed ends of the ducts, which results in plugging them. It then becomes necessary to chip again. In deciding how thick a chip should be taken off, or how much the "face" or scar should be increased in height to give a new flow, it should be remembered that the bulk of the resin is produced in the region between the wound and a point about two inches above it. For this reason, no more of the wood immediately above the old wound should be removed than is necessary to open up the ends of the resin ducts in which the gum has hardened. Since in the space of a week the resin does not harden in the ducts for a distance greater than one-fourth inch from the surface of the cut, a chip that increases the height of the face one-fourth inch is all that is necessary. In practice, the vertical height of the new streak frequently exceeds 1 inch, thus eliminating practically one-half of the wood where most of the resin is being produced, and decreasing the productive period of the tree four times as rapidly as necessary. With the present type of tool it is difficult to cut a one-fourth inch streak, and, moreover, the difficulty of changing an old established custom again presents itself. The chipping tool should always be sharp. A dull edge tends to crush the ends of the resin ducts instead of cutting them clean, thus preventing a free flow.

Frequency of chipping.—Table 8 shows the rate with which the gum flows.

TABLE 8.—*Rate of exudation of gum from "chipped" longleaf pine.*

Day.	Grams of gum.	Total exudation.	Day.	Grams of gum.	Total exudation.
		Per cent.			*Per cent.*
First	113.0	67.26	Fifth and sixth	9.0	5.36
Second	22.5	13.39	Seventh	1.0	0.59
Third	13.5	8.04			
Fourth	9.0	5.36	Total	[2] 168.0	100.00
Fifth	[1]				

[1] No weighing. [2] 168 grams equal 0.37 pound.

It is seen that 88 per cent of the total flow occurs during the first three days. As the resin ducts become plugged with coagulated or crystallized gum the flow gradually ceases, and the gum thereafter produced is stored in the resin ducts until the ends are again opened. When the ducts immediately above the wound become full, the resin tends to diffuse or soak into the wood further removed from the bark This diffused resin does not drain out when the tree is wounded, and for this reason chipping should be done often enough to insure that the active ducts immediately beneath the bark and above the wound will not remain full of gum. On the other hand time should be allowed between chippings for a new supply of gum to form. In practice, trees are chipped once a week. It is possible that more frequent chipping would give a greater yield of gum for a short period (one or two years), but at the same time it might further reduce the vitality of the tree and so result in a smaller total yield over a longer period. The increased yield, moreover, must be enough to justify the additional expense. Experiments are needed to show how the rate of flow is affected by frequency of chipping in operations extending over different periods of years.

Size and number of faces.—The scar on the tree caused by successive chippings is usually about 14 inches wide, and is known as the "face." Wounding the tree, of course, diminishes its vitality by interfering with the transmission of water from the roots to the leaves and of nutritive matter from the leaves to the roots. When a small tree, 8 or 10 inches in diameter, is chipped, it usually either dies outright or its further growth is greatly retarded, even though the width of the face is kept at the minimum.

PRINCIPLES UNDERLYING THE DISTILLATION OF CRUDE GUM.

The crude gum was formerly distilled without the addition of water; in consequence the quality of the resulting turpentine and rosin was poor. The yield of turpentine was very low, but it was impossible to increase it without coloring the liquid yellow with the

decomposition products of the rosin. Other conditions being the same, the question of obtaining water-white turpentine and rosin depends largely on the temperature.[1] The introduction of the practice of using water during the distillation increased the yield and quality of the turpentine and resulted in rosin of a lighter color.

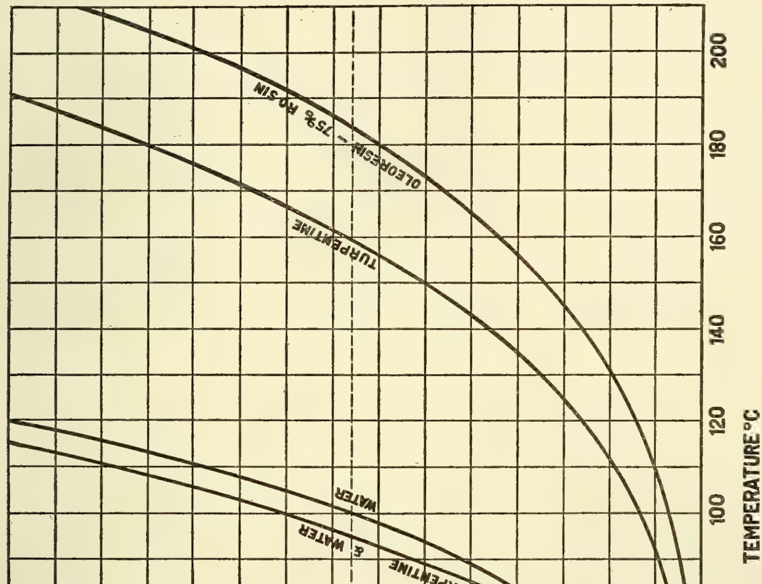


FIG. 2.—Relation of vapor pressure and temperature for turpentine, water, and mixtures.

Turpentine begins to boil at about 313° F.[2] and the greater portion of fresh turpentine distills between 317° F. and 324° F. (See fig. 2). If an attempt is made to distill turpentine direct from a gum contain-

[1] It should be borne in mind, however, that it is impossible to make light rosin from scrape and dip from old boxes or when the gum contains large amounts of trash by following the ordinary methods of production. See p. 27.

[2] 203° F. = 95° C. 302° F. = 150° C. 324° F. = 162° C. 207° F. = 97° C. 313° F. = 156° C. 363° F. = 184° C. 212° F. = 100° C. 317° F. = 158° C. 392° F. = 200° C.

ing 75 per cent rosin and 25 per cent turpentine, the turpentine in the absence of water will not begin to boil at 313° F., but at about 363° F., owing to the presence of the rosin. Rosin does not begin to decompose perceptibly until a temperature of about 392° F. is reached, but after the turpentine in the gum begins to distill off at 363° F., the temperature of the gum rises rapidly. For this reason, only a portion of the turpentine will be obtained before the decomposition of the rosin begins. In fact, it would be impossible to obtain all the turpentine in the gum, and that secured would be yellow, while at such high temperatures the rosin would also be quite dark. Practice has shown that the best quality of turpentine and rosin is obtained at a temperature of 302° F., which calls for the use of water in the distillation.

A liquid begins to boil when the pressure of its vapors is equal to or slightly exceeds the pressure of the atmosphere. Thus, water boils at 212° F. and turpentine at 313° F. Turpentine and water are nonmiscible liquids, and according to physical law will distill together when the sum of their vapor pressures equals the vapor pressure of the atmosphere. Theoretically a turpentine, with a constant boiling point of 313° F., and water will distill together at a temperature of 203° F., the proportion of water and turpentine in the distillate remaining practically constant until one of the liquids is exhausted. Owing, however, to the complex nature of ordinary turpentine with its wide range of boiling points, turpentine and water will begin to distill at about 203° F., and the temperature will rise finally to about 212° F. The distillate will at first contain about 60 per cent of turpentine by volume, the turpentine content of the distillate gradually decreasing to practically zero.

In a mixture of gum (containing 75 per cent rosin and 25 per cent turpentine) and water, distillation will not begin at 203° F., as in the case of pure turpentine and water, but at 207° F. As the gum grows poorer in turpentine the temperature rises until 212° F. is reached. At this temperature all the turpentine will have distilled over.

In actual practice all the turpentine does not distill at 212° F. when water is added, owing to the physical difficulty of bringing more than the surface of the gum in contact with the water. On this account the gum must be heated to a temperature that will make it readily fluid and produce convection currents in lieu of stirring. If live steam were introduced into the mass all the turpentine could be removed below 212° F.

COMMERCIAL METHODS OF COLLECTING CRUDE GUM.

BOX SYSTEM.

Cutting the boxes.—The first operation in turpentining by the box method consists in cutting a cavity (fig. 3) into the base of the tree for holding the crude gum. This cavity, called the "box" is cut

during the winter months. The work is performed by a squad of six or seven negroes under an experienced overseer, who tallies the boxes. The cutting is done by piecework, and each negro has a number which he calls as soon as he has finished a box. The tool used is an ax with a long narrow blade. An experienced man will cut a box

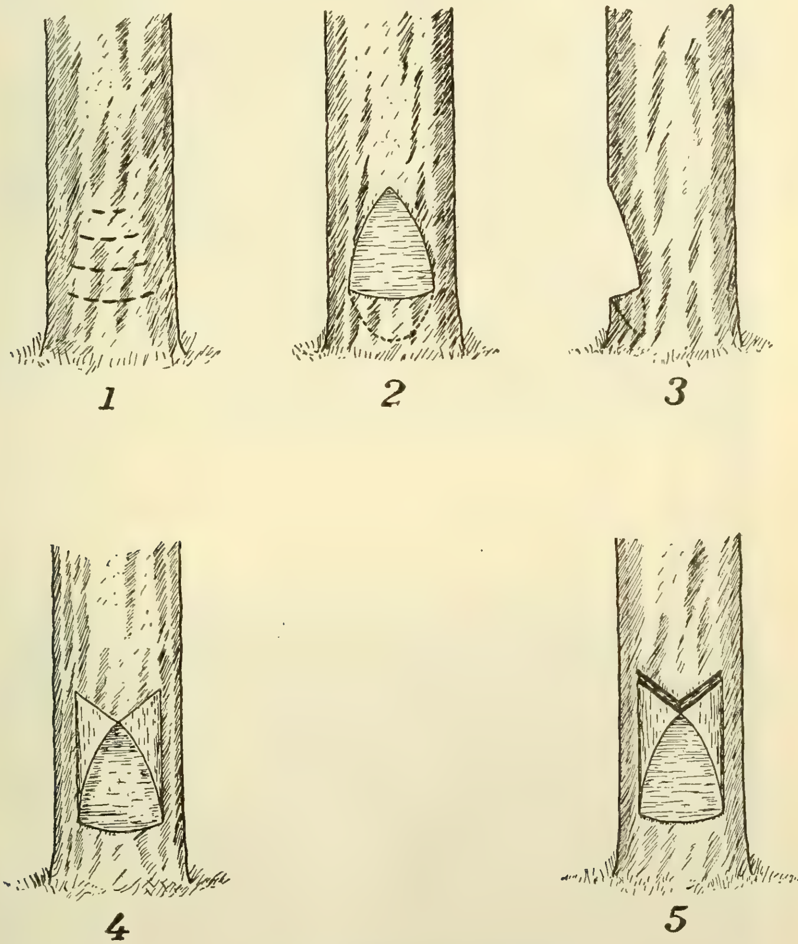


FIG. 3.—Operations in cutting a "box."

1. First step in cutting box. Gashing tree.
2. Finished box. Front view.
3. Finished box. Side view.
4. Cornered box.
5. First streak.

with surprising neatness in from four to eight minutes. The dimensions of the box vary somewhat with the size of the tree. Usually a box is 12 to 14 inches wide, 7 inches deep, 3½ to 4 inches from front to back, and holds about 3 pints. Shaped like a distended pocket, it is cut into the base of the tree 8 to 12 inches above the ground,

although in second-growth timber this distance may be only from 5 to 6 inches.

The position of the box depends on the configuration of the tree. If the latter leans, as is usually the case, the first box is placed on the side opposite to the direction in which it leans, which is generally the position occupied by the most prominent root. When additional boxes are cut on a leaning tree, the loss occasioned by the gum falling outside the box increases each year the tree is bled; in some cases little, if any, resin reaches the box from the fourth year's chipping.

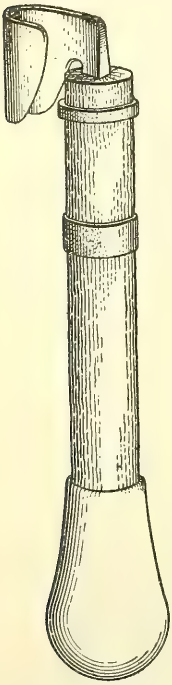


FIG. 4.—Hack with handle and weight.

Cornering.—Two or three weeks before the chipping season opens the "boxes are cornered" (fig. 3 (4)). The operation, which is done with an ordinary ax, consists in removing a triangular chip about 1 inch thick above the corners of the box, a right-handed and a left-handed man usually working together. The chip is removed by making one gash which rises obliquely from the apex of the triangular opening of the box and another gash which rises perpendicularly from the corner of the box to meet the former. This operation serves to form both a surface for future chipping and channels for guiding the flowing gum into the box.

Chipping.—The scarification of the tree, or chipping, begins in early spring, usually in March, and continues each week up to October or November, when the flow of gum practically ceases. The number of chippings is usually 32 per season, although owing to weather or labor conditions it may vary between 28 and 35.

The instrument used for chipping or making the "streak" is called a "hack" (fig. 4). It consists of a flat, steel blade 2½ inches wide, bent into the shape of a U, measuring an inch between the sides.[1] The blade is fastened at right angles to one end of a wooden handle 18 inches long and 2 inches in diameter, to the opposite end of which is attached a pear-shaped iron weight weighing from 5 to 7 pounds; the blade and handle weigh about 1 pound.

The chipper (Pl. I, fig. 1) stands directly in front of the face and removes with the hack two strips of wood and bark one-half to three-fourths of an inch wide and one-half to 1½ inches deep, parallel with the oblique gashes made in cornering. The removal of the two strips constitutes the "streak," which is in the shape of a V, having an angle of about 95°. The apex of the angle is called the "peak" and

[1] Three sizes of hacks are made. The blade described is for a No. 1 size hack.

FIG. 1.—CHIPPING.

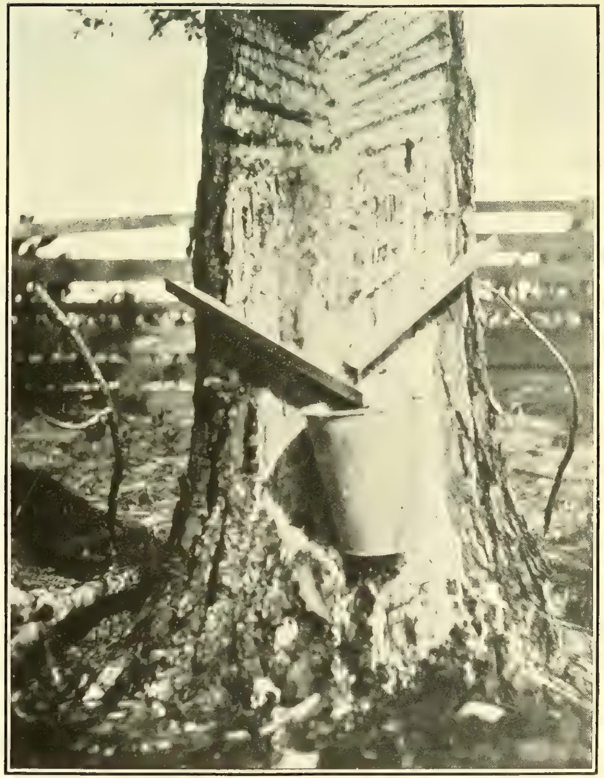


FIG. 2.—CUP AND GUTTERS.

Blaze below first streak 8 by 16 inches. Distance from gutter to peak of first streak 8½ inches, of which 7 inches, equivalent to 14 streaks, represents a loss of possible chipping height.

"PULLING."

This tree originally boxed; cups substituted later.

lies directly above the center of the box. The hack is given a quick, swinging motion, and the momentum furnished by the iron ball enables one side of a streak to be made with only two or three blows. Chippers are paid from 75 cents to $1 per thousand streaks, according to the condition of the crop and the scarcity of labor.

After the first two seasons the increased height of the face makes the use of a hack impracticable, and a "puller" is used in its place. This tool resembles the hack, except that the blade is closed and provided with a long handle. The streak is made by a steady pull (Pl. II) rather than with a quick hacking motion. After the fourth season the face is usually abandoned, since at that time a height of 8 feet is attained, beyond which it is not profitable to work a tree. Old faces 12 feet in height have been noted in Georgia, and others even higher in North Carolina and South Carolina.

Dipping.—The boxes fill with gum in three or four weeks and are "dipped" or emptied about seven times a season. The workman uses a tool called a "dipper", which has a flat trowel-shaped blade about 7½ inches long and 5½ inches wide. This dipper is thrust into the box under the gum, which is removed by a quick upward and outward motion and flipped into a portable bucket. Considerable skill is required to prevent loss of gum during the transfer. The bucket is emptied into barrels placed at convenient points throughout the woods. These barrels, provided with removable heads, are closed after filling, rolled upon wagons by means of skids, and taken to the still. Dippers receive from 50 cents to $1 per barrel, according to the nature of the territory covered.

Scraping.—A certain amount of the gum does not reach the box, partial evaporation of volatile oil leaving it too viscous to flow. Gum which is perfectly homogeneous and transparent immediately after exudation soon becomes opaque from the separation of white crystals of the resin acids, and doubtless the greater portion of the "scrape" results from the adherence of these separated crystals to the face. The amount of this hardened gum naturally increases with the height of the face. "Scrape" is essentially a product of longleaf pine (*Pinus palustris*), since slash pine (*Pinus heterophylla*) forms but small amounts, which it does not pay to collect. The scrape contains about half as much turpentine as the "dip" and gives a darker resin under similar conditions.

The scrape is collected but once a year—at the end of the season. The tools used, called "scrapers," are of two types. One type, the "pusher," has a flat, rectangular blade 4 inches long by 4½ to 5 inches wide. This is used during the first two years, the scrape being removed by downward thrusts of the tool. In most cases the necessary violence of the thrust results in removing large chips of wood along with the scrape. Another type of scraper has a blade shaped

like an equilateral triangle and in use is given a pulling motion downward.

The scrape is usually collected and distilled before the last dipping is made, since at the end of the season the danger of fire breaking out in the woods and burning the faces is very great. The dip in the boxes is not so great a source of danger, since it is usually more or less covered with water. In course of removal the scrape is considerably disintegrated, and if stored in the rosin barrels for any length of time the turpentine evaporates rapidly.

A wooden box, called a "scrape box," is used to receive the detached scrape. This box is about 2½ feet square and open at the top and at one end. The bottom at the open end is rounded inward and provided with an apron of burlap to form a close contact with the tree and prevent loss of scrape. The legs project sufficiently above the sides to serve as handles for dragging the box from tree to tree, though sometimes the box is provided with wheels. A box will hold from 100 to 150 pounds of scrape, which is transferred to rosin barrels and hauled to the still.

Raking.—After the crude gum has been collected the trash surrounding the base of the tree is "raked" away for a distance of 2½ to 3 feet to guard against fire. This operation is performed late in the fall, the tool used being a hoe with a broad, heavy blade. The turpentine woods are intentionally burned over once each season, to afford better forage for stock the following spring, to reduce the risk from accidental fires, and to remove brush and other materials which impede the workmen.

Crops.—The tracts of timber to be turpentined are divided into sections called "crops," a full crop consisting of 10,500 boxes.[1] Since each tree receives from one to four boxes, 4,000 to 5,000 trees, covering an area of 200 to 250 acres, are required to make one crop. For convenience in working, the crop is further divided into drifts, whose boundaries are defined by lines blazed on the trees. Each drift contains about 2,100 boxes, although this number varies considerably.

The average still has a capacity of 15 to 20 barrels, so in order to make two distillations per day with a still holding 20 barrels of crude gum the operator must work 20 crops, covering an area of four to five thousand acres. It is seldom profitable to work less than five crops.

CUP SYSTEMS.

Historical.—Until recent years the box system was the only one used in the United States for collecting resin. While no recent figures are available, it is probable that at present the number of cups

[1] In practice a "crop" consists of the number of faces a man can chip in from four to five days. Consequently a "crop" may vary from 7,000 to 10,000, owing to the topography of the country or density of the stand.

in use exceeds the number of boxes. During the past two or three years, however, it is estimated that cups have been hung on 75 per cent of the trees tapped.

The need of replacing the box with a cup hung against the tree was felt many years ago.

Mr. A. Pudigon patented a substitute for the box in 1868, and the device received a commercial test at Monks Corner, S. C., but was soon abandoned for some unknown reason. From that time on numerous substitutes have been invented, but none patented prior to 1903 proved a commercial success.

The first systematic attempt to improve the method of collecting gum was made at Bladenboro, N. C., by W. W. Ashe in 1894. A comparison on a limited scale was made between the French cup and gutter system and the box system, and the results showed a gain for the former of over 20 per cent in the value of the products collected.

The preliminary experiments begun in 1901 by Dr. Charles H. Herty, of the Forest Service, and continued in 1902, mark the turning point in the method of collecting crude gum. Cups were first used on an extensive scale in 1904, and since that time their use has become more or less general.

Classes of cup systems in use at present.—The cup systems may be divided into four classes.

Class 1. (Plates III and IV.) The gum flowing down the face is guided into the cup by means of two galvanized-iron gutters inserted in cuts in the tree. These gutters are 2 inches wide and from 6 to 12 inches long, depending on the size of the tree, and are bent into an obtuse angle. Sufficient bark and sapwood are removed from the tree to form a central vertical ridge with two flat faces on either side of it. The gutters are inserted in inclined gashes made by a broadax in the flat surfaces. It is necessary that these surfaces be flat, in order that the straight edge of the gutter may enter the face along its entire length, so that gum can not flow between the gutter and the tree. The lower gutter is placed so as to project at least two inches beyond the other at the center of the ridge, in order to guide the gum into the cup, which is hung just below the lower gutter on a nail. The cups are of galvanized iron or of clay, and vary in shape. Those resembling an ordinary flowerpot are the most common. Their capacity is 1, $1\frac{1}{2}$, or 2 quarts. The blazes made for inserting the gutters extend below the latter and produce a flow of resin which is not only wasted but serves to coat the base of the tree, and thus makes the face more susceptible to fire. The workman frequently makes the blaze too large, as is shown in Plate III, figure 1, and there is a tendency in placing the gutters to spread them too far apart, losing in many cases as much as 20 inches of chipping surface. It is entirely possible to place the cups and gutters on a normal tree so that the first streak

will be 12 inches from the ground (Plate III, fig. 2). In Plate IV, figure 1, the first streak is 17 inches higher than necessary. On the basis of one-half inch streaks this means that a height sufficient for 34 chippings, or for a whole season, has been lost.

Class 2. (Plates V and VI.) The gum flowing from the face is guided into the cup by means of a flat oblong piece of galvanized iron, with the ends slightly upturned, called an "apron." The edge of the apron to be inserted in the tree is concave to conform to the tree's shape. In some cases the aprons are made in two pieces, riveted together at the ends, so as to allow them to be adjusted to the curvature of each particular tree. They are also made in two separate pieces. The aprons are inserted in a horizontal gash at the base of the tree made with a broadax having a flat blade with a concave edge. When inserting the apron a small blaze about 6 inches wide and 2 inches high is generally made to remove objectionable bark. The broadax is held horizontally against the blaze, with the head slightly downward, by one man, while another drives it into the tree with a maul. The ax is then withdrawn and the apron inserted.

A recently introduced apron is lunar in shape, the concave edge being provided with stiff teeth. This apron can be driven directly into the tree, obviating the necessity of blazes or gashes.

The cups are made of galvanized iron or clay and hold about a quart. Their general shape is that of an oblong box 12 inches by 3 inches at the top, and about 3 inches deep. They are slightly larger at the top than at the bottom, and are sometimes shaped to conform to some extent to the curvature of the tree. The cups are sometimes hung from the apron by means of small hooks which engage an extension on either end of the apron, or they may be supported on a nail driven into the tree beneath the apron. The likelihood of the fasteners becoming clogged by gum is obviated by the use of nails as supports. In hanging this class of cups large blazes are not necessary, and if properly hung practically all the gum flowing from the tree reaches the cups. As the aprons occupy but little vertical space and the cups are comparatively shallow, a distance of 12 inches from the ground to the first streak is ample on normal trees (Plate V, fig. 1). In the case of small trees 10 inches or less in diameter, the use of the 2-piece or riveted apron allows a shallower cut to be made in hanging the cup, as the 1-piece aprons have such a large curvature that they require a deep cut in small trees (Plate VI, fig. 1) to prevent escape of gum at the sides. On large timber, of course, this difficulty does not occur.

Class 3. (Plate VII, fig. 1.) The cup is so constructed as to obviate the necessity of using a gutter or apron. In order to hang it, several

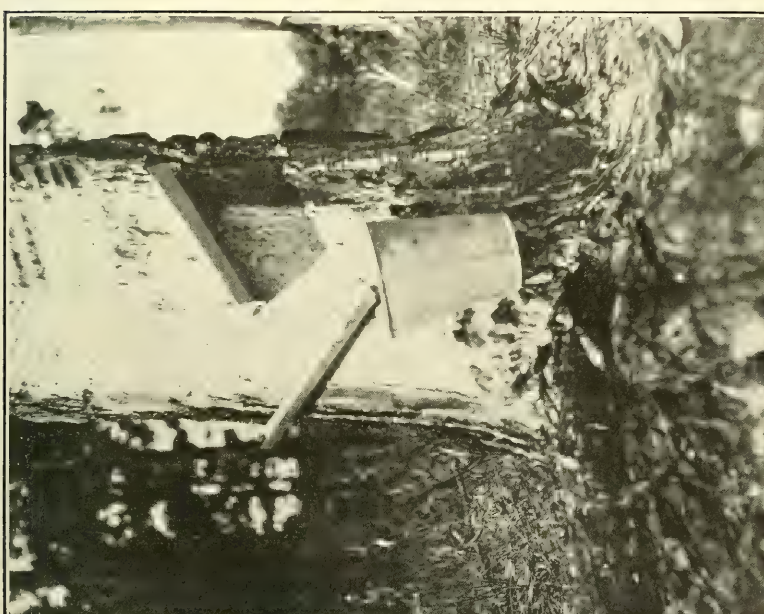


FIG. 1.—CUP AND GUTTERS.

Twenty-one inches from ground to first streak, 5 inches between gutters, 6 inches from first streak to lower end of upper gutter Note large useless blaze 16 by 9 inches below first streak. Nine inches of chipping height have been lost.

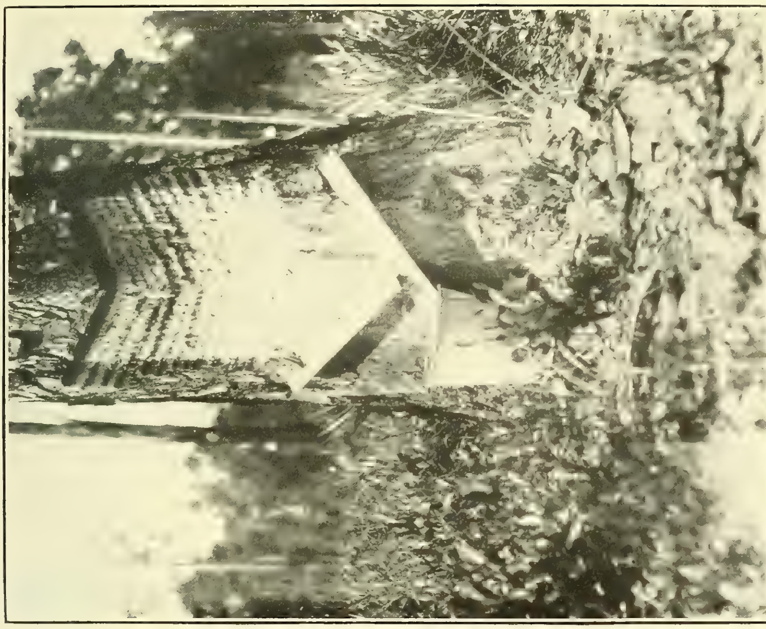


FIG. 2.—PROPERLY HUNG CUP AND GUTTERS.

Twelve inches from ground to first streak.

FIG. 1.—BADLY HUNG GUTTERS.

Twenty-nine inches from ground to first streak. Seventeen inches, or nearly a year's chipping height, has been lost.

FIG. 2.—CUP AND GUTTERS.

Lower gutter projects too far. Five inches from lower gutter to first streak.

streaks are made at the base of the tree, the last one being a "shade" streak or one which is undercut. The prolonged back of the cup is notched and bent to conform to the chipped surface. The cup is loosely hung on a nail, so as to be readily detachable for dipping. The first chipping is so made as to leave a band of bark and wood $1\frac{1}{2}$ to 2 inches wide over which the resin flows and drips into the cup. The last chipping of the season should be a shade streak, so that at the beginning of the succeeding season the cup may be raised and fitted under it and a strip of bark and wood left as before.

Great care must be used in hanging these cups or the loss of resin will be excessive. It is difficult to make a shade streak close to the ground, and if a square streak is made the resin will flow between the tree and the cup. The cup in Plate VIII, figure 1, was originally hung so poorly that rehanging was necessary in the middle of the first season. The equipment for hanging cups of this class is simpler than in the case of those requiring gutters and aprons, and the necessity of gashing the tree with a broadax is obviated.

Class 4. (Plate VII, fig. 2.) Two gutters of galvanized iron are inserted in a streak just above the cup which is hung on a nail. The gutters are semicircular in section and the ends are so riveted together that the gutter may be adjusted to any angle. To hang the gutter, a shade streak is made and the gutter fitted into it and held in position by means of two nails driven through holes made for the purpose.

This gutter can be hung by one man and no special tools are required. No wounding is necessary, except a single streak; and, owing to the rivet, the gutter will serve readily for small and large timber. Unless care is used in placing these gutters, however, the gum will flow between them and the tree.

Class 5. The gum flows from two holes bored diagonally upward into the tree from a common point. The top of the receiving vessel consists of two caps at right angles, connected by a triangular tube. One cap is placed over the holes bored into the tree, while a glass cup screws into the horizontal cap. When full, the cups are unscrewed and emptied. When the flow ceases, the old holes are reamed out or new ones bored. Experiment has shown that the holes in the tree, as well as the tube in the receiving vessel, soon become plugged with gum, rendering the maintenance of a continuous flow an expensive operation. This method of tapping is worthy of mention, however, since by its means two highly desirable results in naval stores operations are obtained, namely, a pure gum and minimum damage to the timber.

Material and shape of cups.—The great majority of cups on the market are made of clay or galvanized iron. The clay ones are the cheaper, and it is claimed for them that they yield a higher quality

of gum, since clay does not become heated like metal when exposed to the sun and thus cause evaporation of the turpentine. Clay cups are three or four times as heavy as metal cups, however, and much more bulky. They are also more likely to break, both in transit and in handling. On the other hand, they do not rust like the galvanized-iron cups. Rusting not only results in loss of cups, but may also darken the gum.

In shape the cups may be like a flowerpot (Plate I, fig. 2), an oblong box (Plate V, fig. 1), or a flattened cone (Plate VII, fig. 2). With the deep cups, it is claimed, there is less evaporation of gum, on account of the smaller surface exposed. On the other hand, deep cups take up more vertical height on the tree, and are generally considered more difficult to dip. The cone-shaped cups are similar in shape to the interior of the ordinary "box," being so made for the sake of economy, since only one seam is necessary.

Within certain limitations the kind of cup used with a particular gutter or apron is immaterial. Between the cups and gutters now on the market, the greatest room for improvement exists in the case of the latter, though improved aprons and gutters are constantly put on the market.

RELATIVE YIELDS SECURED FROM CUPS AND BOXES.

Experiments made by the Forest Service in Georgia during 1902 showed conclusively that more and better turpentine and rosin can be obtained by the use of cups than by the use of boxes.

The timber studied consisted of a first, second, third, and fourth year crop, one-half of each crop being turpentined by the cup system and the other half by the box system. The comparative results are shown in Tables 9 and 10.

TABLE 9.—*Spirits of turpentine from eight half crops, season of 1902, Georgia.*

Half crops.	From dip.	From scrape.	Total.	Excess from cupped trees.	
	Gallons.	*Gallons.*	*Gallons.*	*Gallons.*	*Per cent.*
First year:					
Cups	1,385.3	205	1,590.3	301.9	23.43
Boxes	1,134.7	153.7	1,288.4		
Second year:					
Cups	1,087.2	188.2	1,275.4	66.6	5.51
Boxes	941.8	267	1,208.8		
Third year:					
Cups	726.5	113	839.5	310.1	58.58
Boxes	381.9	147.5	529.4		
Fourth year:					
Cups	687.2	101	288.2	314.2	66.29
Boxes	349.5	124.5	474		

TABLE 10.—*Net rosin sales from eight half crops, season of 1902, Georgia.*

Half crops.	From dip.	From scrape.	Total.	Excess sales from cupped trees.	
				Net.	*Per cent.*
First year:					
Cups	$401.72	$47.72	$449.44	$85.51	23.50
Boxes	328.40	35.53	363.93		
Second year:					
Cups	266.34	49.25	315.59	144.13	84.64
Boxes	104.51	66.95	171.46		
Third year:					
Cups	171.27	27.44	198.71	132.65	200.80
Boxes	39.49	26.57	66.06		
Fourth year:					
Cups	167.33	29.23	196.56	132.56	207.13
Boxes	36.09	27.91	64.00		

The first year crop mentioned in Tables 9 and 10 was worked for two years longer. The combined yields obtained for the "cupped half" and "boxed half" during the 3-year period of operation are given in Tables 11 and 12.

TABLE 11.—*Spirits of turpentine from half crops, seasons 1902–1904, Georgia.*

Year.	Cups.			Boxes.			Excess from cupped half crop.	Net price per gallon at time of operation.	Value of excess from cupped half crop.
	Dip.	Scrape.	Total.	Dip.	Scrape.	Total.			
	Gallons.	*Gallons.*	*Gallons.*	*Gallons.*	*Gallons.*	*Gallons.*	*Gallons.*	*Cents.*	
First	1,385.3	205.0	1,590.3	1,134.7	153.7	1,288.4	301.9	40	$120.76
Second	1,103.5	165.0	1,268.5	705.2	226.6	931.8	336.7	45	151.52
Third	781.3	136.0	917.3	536.1	190.5	726.6	190.7	45	85.82
Total	3,270.1	506.0	3,776.1	2,376.0	570.8	2,946.8	829.3		358.10

TABLE 12.—*Net sales of rosin from half crops, seasons 1902–1904, Georgia.*

Year.	Cups.			Boxes.			Value of excess from cupped half crop.
	Dip.	Scrape.	Total.	Dip.	Scrape.	Total.	
First	$401.72	$47.72	$449.44	$328.40	$35.53	$363.93	$85.51
Second	286.88	58.24	345.12	132.42	84.08	216.50	128.62
Third	212.60	61.65	274.25	124.76	79.70	204.46	69.79
Total	901.20	167.61	1,068.81	585.58	199.31	784.89	283.92

RELATIVE AMOUNTS OF SCRAPE FORMED BY THE BOX AND CUP SYSTEMS.

The resin obtained from trees turpentined by the box method must flow an increasingly greater distance each year the tree is tapped. As a result the amount of scrape formed is proportionately increased. The proportion of scrape formed by the two systems is shown in Table 13.

TABLE 13.—*Comparison of the amount of scrape formed by the cup and box systems, season 1902, Georgia.*

Half crop.	Net weight of scrape.	Net weight of dip.	Total weight of "gum" dip and scrape.	Percentage of scrape.
	Pounds.	*Pounds.*	*Pounds.*	*Per cent.*
First year:				
Boxes	10,315	42,787	53,102	19.4
Cups	13,155	51,081	64,237	20.5
Second year:				
Boxes	17,120	35,700	52,820	32.4
Cups	12,210	42,630	54,840	22.3
Third year:				
Boxes	8,580	15,435	24,015	35.7
Cups	7,200	28,245	35,445	20.3
Fourth year:				
Boxes	7,970	14,385	22,355	35.6
Cups	6,635	25,305	31,940	20.8

Scrape is troublesome to collect, yields a low grade of resin, and gives but 11 per cent of turpentine on distillation, while gum collected by the cup system yields about 19 per cent of turpentine.

RELATIVE YIELDS FROM DIFFERENT DEPTHS AND HEIGHTS OF CHIPPING.

In the years 1905 to 1908 the Forest Service carried out experiments to determine the effect of the depth and height of chipping on the yield of resin. Four crops [1] were used in the experiment, designated A, B, C, and D, respectively.

Crop A, taken as the standard, was chipped in the ordinary way, the average depth of chipping being seven-tenths of an inch and the average height five-tenths of an inch.

Crop B was used to test the effect of shallow chipping, the average depth being four-tenths of an inch.

Crop C served to show the effect of narrow chipping, the average height being four-tenths of an inch.[2]

Crop D was turpentined with reference to the possibility of working the turpentine a second time. The present method consists in exhausting the tree within four years. This crop was chipped in the same manner as crop A, but the minimum diameter of the trees turpentined was limited to 10 inches, as compared to a minimum diameter of 6 inches in crop A; in addition the minimum diameter of the tree to bear two faces was raised from 13 inches in A to 16 inches in crop D; no tree in crop D had more than two working faces.

Table 14 shows the yields from the four crops A, B, C, and D.

[1] Crops of 8,000 faces each were used.

[2] It was intended to have the height of chip in "C" half that in "A," but in spite of close supervision the chippers cut wider than was desired.

FIG. 1.—CUP AND APRON.

Twelve inches from ground to first streak, 1½ inches from gutter to first streak, 10 inches from ground to top of cup.

FIG. 2.—CLAY CUP AND APRON.

Fourteen inches from ground to first streak, 3 inches from gutter to first streak.

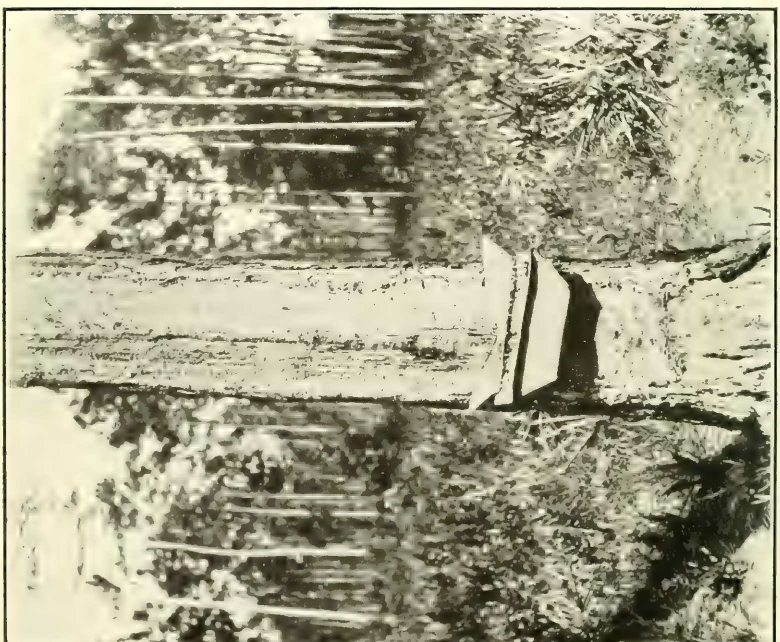


FIG. 1.—CUP AND APRON.

Working face the fourth season and the cup has been raised but once.

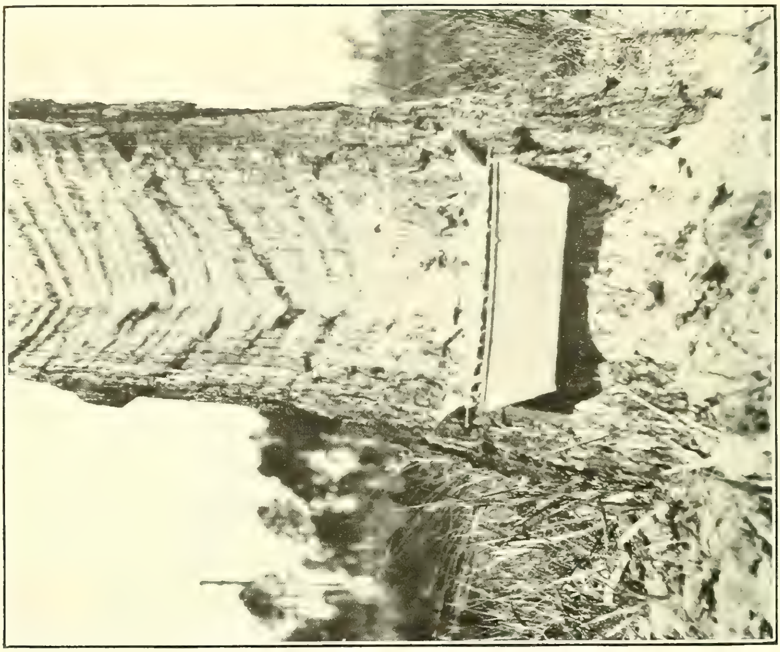


FIG. 2.—CUP AND APRON.

Working second year face without raising cup, thus reducing the efficiency of the cup system.

TABLE 14.—*Summary of total yields for four years based on the dip and scrape being corrected to the same number of chippings per crop (8,000 faces).*

Crop.	Dip.		Scrape.		
	Yield.	Increase.	Yield.	Increase.	Decrease.
	Pounds.	*Per cent.*	*Pounds.*	*Per cent.*	*Per cent.*
A	206,235		47,742		
B	211,911	2.75	44,838		6.08
C	214,503	4.01	39,775		16.69
D	279,260	35.41	53,915	12.93	

Two crops, G and H, were worked for one year, combining the principles observed under crops B and C, namely, shallow and narrow chipping. Crop X was chipped in the ordinary way. Table 15 gives the yields.

TABLE 15.—*Summary of yields for one year. Crops X, G, and H.*

Crop.	Number of cups.	Number of chippings.	Yield of dip.	Increase.
			Pounds.	*Per cent.*
X	9,880	35	90,094	
G	9,880	35	124,292	38
H	9,880	35	121,474	35

As seen from Table 15 there is a decided increase in yield by the use of shallow and narrow chipping.

EFFECT OF TURPENTINE OPERATIONS ON TIMBER.

INJURY FROM FIRE.

Since the box is rarely more than 12 inches from the ground, it is within easy reach of ground fires. As both box and face are saturated with resin, a fire once started in the box may burn the tree off at the base or render the face and box unfit to produce gum. In cupped timber the cups are moved up at the end of the season and are less exposed to fires.

Another source of fire arises from the resin which impregnates the ground at the base of the tree. Such resin may come from losses in dipping, overflow from boxes on very productive trees, or from leaning trees. This waste resin may defeat the entire purpose of raking. Spilling is less likely to occur with cups than with boxes, since the former can be detached and held directly over the bucket in dipping. By having extra cups for very productive trees the chipper who visits them weekly can quickly change the full cups for empty ones and thus prevent overflow.

The immediate danger of destruction of the timber is not so great while the trees are being turpentined as when the crop has been abandoned, since during the period of active operation the trash is raked from about the trees. Few tracts of timber escape the annual burning over, and turpentined trees are often either killed directly or permanently injured. While the damage to abandoned cupped timber is heavy, it is not so serious as in boxed timber, since the cups are removed when the trees are abandoned and the faces are the only source of fire risk.

INJURY TO GROWTH.

The box enters the tree so deeply as to injure its vitality and retard the process of growth. Boxes are generally cut in the most prominent root swellings, especially in leaning trees, as when so placed they will more readily catch the gum and are also easier to cut. The box undoubtedly curtails the food supply of the tree to a considerable extent and accounts for the fact that more "boxed" than "cupped" trees die after tapping.

The box weakens the tree so that it is liable to be blown down by the first storm. This is especially true of small timber which may have from one-half to two-thirds of its diameter severed by the box, and of timber in old orchards that has been "back-boxed," i. e., boxes cut between the old ones wherever there is available space.

The following tabulation compares the number of dead and blown-down trees in half crops worked with cups and boxes for one season:

	Trees blown down.		Trees dead.	
	Boxed.	Cupped.	Boxed.	Cupped.
After 16 chippings	5	1	2	1
After 32 chippings	8	3	35	16

Since the box fills with water after the trees are abandoned, the surrounding wood is kept moist, increasing the likelihood of attack by fungi and subsequent decay. In some cases the box is filled with earth after abandonment to prevent it from catching fire. While it may serve the latter purpose, the procedure is scarcely to be recommended, since the earth retards evaporation of the water and hastens decay.

Trees that have been "boxed" are sometimes attacked by bark-boring and wood-boring insects, the former killing the trees and the latter seriously damaging the wood.[1]

QUALITY OF LUMBER IN "TURPENTINED" AND "ROUND" TIMBER.

The wood back of the "faces" in timber that has been turpentined for several years is generally impregnated with resin for a depth of from one-half to one and one-half inches. As very resinous material

[1] See U. S. Department of Agriculture Farmers' Bulletin 476, and Yearbook 1909, pp. 410–412.

will not make high-grade lumber, the proportion of high-grade material that can be cut from "turpentined" timber is somewhat less than in the case of similar "round" timber. However, in many cases the process of squaring up the log by sawing off slabs will remove the resinous parts, and the grade of the boards finally cut will not be affected. Tests have shown that the strength of the wood is not altered by turpentining.

QUALITY OF GUM FROM BOXED AND CUPPED TIMBER.

As the height of the face increases, the distance the resin must flow to reach the box increases correspondingly. During its journey the gum is constantly losing turpentine by evaporation. Thus, the percentage of turpentine in the dip decreases each year boxed timber is tapped, while the amount of scrape increases. Cups are designed to be raised each season, and thus the gum has to flow a comparatively fhort distance.

The resin acids in the crude gum readily absorb oxygen, which darkens the rosin. The higher the face the longer the gum is subjected to atmospheric oxygen, so that, with boxed timber, light rosins can be obtained only during the first two years. Another sactor which produces dark-colored rosin is the gum that remains attached to the face after the period of collection has passed. This gum becomes yellow to dark brown, and as the following year's gum flows over it to the box, a certain amount of this highly colored product is always dissolved, so that when ordinary methods are used only the lower grades of rosin are produced from gum coming from five-year boxes. In raised cups the gum flows only over the face made during a single season. In practice, however, the cups are seldom raised after the third year, since this greatly increases the cost of collecting the gum.

COMMERCIAL DISTILLATION OF CRUDE GUM.

The apparatus commonly used in the United States for distilling gum consists of the simplest type of still, with a "worm" for condensing the vapors (Pl. VIII and fig. 5). A shed, generally open on all sides, covers the still proper, and another and smaller building, placed a short distance away as a precaution against fire, is used for storing the turpentine. It also contains the kettle for heating glue to coat the inside of the turpentine barrels. In many cases the still and warehouse are under one roof. A charging platform is built flush with the collar of the still, the barrels of gum being rolled upon it by means of skids.

The capacity of stills varies from 10 to 40 barrels. Fifteen and twenty barrel stills are the most common. The term "20-barrel still" refers to the total capacity of the still and not to the number of barrels of gum in a charge. The size of the latter is determined by

the nature of the gum; the older the gum the smaller the charge. Even with "virgin dip" the still is only filled to three-fourths of its capacity, while with dip and scrape from four or five year "boxes," which foams considerably, only about one-third the capacity of the still is used. If the material rises into the still head there is danger of it forcing an exit between collar and still head and setting fire to the platform.

The still body is about two-thirds as high as wide, with a rounded top and a slightly concave bottom, the latter permitting the rosin to

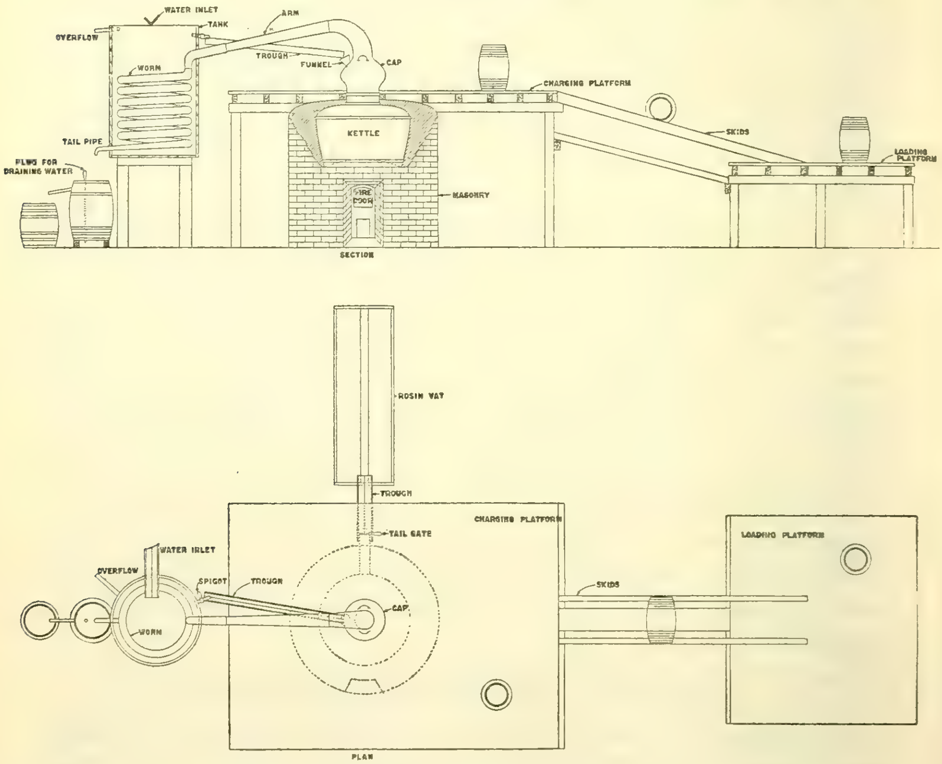


FIG. 5.—Arrangement of apparatus in turpentine still.

drain thoroughly. The still head is generally spherical [1] and is connected with the worm by two sections of pipe called the "arm" and "gooseneck." The worm makes about $6\frac{1}{2}$ turns in a wooden tank holding the condensing water, leaving the tank by means of a short pipe called the tailpiece. The entire apparatus is made of sheet copper. For a 20-barrel still, the side, top ("breast"), and collar of the still proper are made of 14-gauge copper, the rosin spout of 11-gauge, and the bottom of 4-gauge copper. The worm and connecting pipes are made of 18-gauge copper.

[1] Several forms of still head are in use.

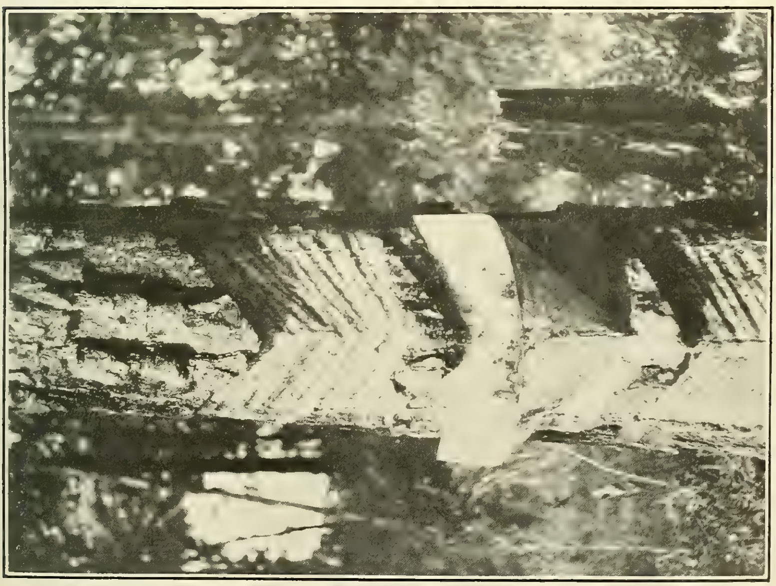


FIG. 1.—CUP WITHOUT GUTTERS OR APRON. SECOND YEAR FACE.

FIG. 2.—ADJUSTABLE GUTTER.

TURPENTINE STILL SHOWING CONDENSER.

Glue vat for coating inside of turpentine barrels on extreme right.

DISTILLATION PROCEDURE.

The still is charged by removing the still head and gooseneck and dumping in the gum from the barrels. After most of the dip has run from the barrels they are thoroughly drained over a special trough. It is hard to remove the dip from the barrels during cold weather, and distillation is not carried on extensively in winter. When scrape is distilled alone, and the still is hot from the previous run, it is customary to pour in 5 or 6 buckets of water or a couple of barrels of dip to cool off the still and prevent the first scrape put in from "burning."

After the still has been charged the cap is put on and connected with the worm by means of the gooseneck. The joints are then luted with clay. The fire is started under the still, and its intensity regulated solely by the peculiar noise made by the gum during distillation. Crude gum always contains a certain amount of water (from 5 to 10 per cent), and since the gum melts rapidly, a mixture of oil and water soon appears at the end of the worm. A distillation requires from 2 to 2½ hours; all the water originally present distills over during the first one-half to three-fourths of an hour. The "stiller" follows the course of the distillation by placing his ear near the lower end of the worm, where the characteristic sounds made by the boiling gum are most audible, and by examining portions of the distillate collected in an ordinary drinking glass and noting the proportions of water and turpentine. The point at which additional quantities of water should be added is indicated by a peculiar strident sound, characterized as the "call for water."

The water added is obtained from the top of the cooling tank. It flows from a cock, by which the size of the stream is regulated, by way of a trough into the still through a funnel placed in an opening in the cap. The water at the top of the tank is always warm, and often very hot. Some distillers obtain this water from the bottom of the tank, claiming that the distillation is easier to regulate with cold water. About 2½ barrels of water are run in for each distillation, the amount varying with the size of the charge.

The critical period during distillation is passed when all the water in the gum has been driven over, since as the water is vaporized it swells the viscous gum to such an extent that it may overflow into the worm or escape through the joints, provided sufficient space has not been left in the still for this expansion. "Dip" and "scrape" from high faces are especially likely to boil over. The tendency to foam over is indicated by the sound of tumultuous boiling at the end of the worm. When this occurs the fire is urged as rapidly as possible, the resinous chips obtained by skimming the gum usually being added, and the increased temperature maintained until the

gum returns to a normal state of distillation. The heat is increased because at the temperature at which the water is vaporized, the gum is still in a viscous condition, and is so tenacious as to form a mass of bubbles whose shells are not ruptured by the inclosed steam; hence the gum swells enormously. In order to remove this water, it is necessary to heat the gum to so fluid a state that the bubbles will burst readily and allow the steam to escape. After this inclosed water has been driven off the distillation usually runs along smoothly, since the water that is added merely comes in contact with the surface of the gum. If excessive foaming takes place after the stream of water has been started, the fire is urged as usual, but the flow of water is not diminished. If the gum should boil over the distillation is spoiled, and must be repeated.

The end of the distillation is reached when a portion of the distillate collected in the test glass shows only a very small proportion of turpentine. All the turpentine is seldom removed, if the distiller wishes to obtain a high-grade rosin. The stream of water is now cut off, and the fire extinguished with water to prevent the rosin from igniting when it is run out, and to prevent scorching the small amount of rosin that always adheres to the bottom of the still.

Skimming.—The gum always contains more or less trash, such as sand, chips, needles, pieces of bark, etc. This all goes into the still along with the gum, and is removed at various stages during the distillation. The chips are removed with a skimmer, 16 inches long by 14 inches wide, made of wire netting and attached to a long handle.

Except in the case of dip collected at the end of the season, skimming is done as soon as the charge is fluid. In other cases skimming is done either at the point when the water originally present in the gum has passed over, or at the end of the distillation when the rosin is ready to be run off. When the gum contains a considerable amount of trash, especially bark and needles, a lighter resin will be obtained by skimming before distillation. However, in the case of "old stuff," there is considerable difficulty in getting the charge fluid enough for skimming without excessive loss of turpentine and the danger of foaming.

TREATMENT OF THE ROSIN.

After the distillation is ended, the rosin, at a temperature of 302° to 392° F., is run out by means of a pipe extending flush from the bottom of the still and closed by a gate valve. Usually the rosin flows through a set of four screens into a vat sunk into the ground. One, two, or three screens may be used, however, instead of four. The vat is about 4 by 15 feet at the bottom, 4½ by 15 feet at the top, and 2½ feet deep. The screens are sufficiently large to cover it, with the exception of the top one, which is only half the length of the still, and is intended to catch only the coarsest chips. The top screen is

from 6 to 8 mesh, the second 14 mesh, the third 32 mesh, and the bottom 60 mesh. The bottom screen is covered with a layer of cotton batting to remove the finer particles of dirt.

The rosin remains in the vat from a few minutes to an hour, according to the temperature at which it left the still. It is next dipped into crude barrels made on the spot, holding about 450 pounds net. If dipped while too hot and fluid, considerable leakage occurs between the staves, which may in a measure be prevented by luting with clay. The rosin requires about 24 hours to become solid.

The cotton batting, after being used to strain the rosin, is known as "batting dross" or "rosin dross." As cotton is very absorptive, a large amount of rosin is retained. Recent analyses made by the Forest Service indicated that rosin dross contains from 75 to 90 per cent by weight of rosin.

It has been the practice to burn under the still a certain portion of the chips removed by skimming and in the screens, and to throw away the rest. In this way, piles of discarded chips often grew to large size before the stills were moved. Such piles, of course, contain considerable rosin, and during 1911 and 1912, owing to the high price of naval stores, operators found it profitable to sell not only the dross, but the skimmings and similar material to extraction plants.

TREATMENT OF THE TURPENTINE.

The distillate issuing from the worm, and consisting of a mixture of water and turpentine, runs into an ordinary 50-gallon barrel, where the separation of the water and turpentine takes place by gravity; the turpentine, being lighter, floats on the top. The bottom of this barrel contains an opening, closed with a long wooden plug, by which the excess water is allowed to escape as the volume of the distillate increases. In most cases a second container, consisting of a barrel whose upper half has been sawed off, receives the turpentine flowing from the top of the first barrel through a short pipe, to permit of more perfect separation. A thin yellow scum forms the line of demarcation between the water and turpentine. The latter is dipped out carefully and poured directly into the barrels in which it is sent to market.

The first runnings of turpentine are colored more or less green with copper salts, due to the action of acetic and resin acids on the copper of the worm and still. The green color is especially noticeable when the still is first used after a period of idleness. When the still is in continuous use the color in the first runnings is very slight.

The turpentine barrels must be thoroughly tight. They are usually made of sound white oak, thoroughly driven, and coated on the inside with glue. Each barrel holds about 50 gallons, some space being left for expansion of the contents.

FRENCH METHODS OF COLLECTING GUM.

MANAGEMENT OF FORESTS.

A large proportion of the French forests exploited for resin are situated along the coast, where the shifting sand dunes have been planted with maritime pine (*Pinus maritima*).

The forest rotation varies from 60 to 75 years, and since maritime pine is a prolific seeder, a new growth readily springs up on cut-over areas. At the end of 10 years the stand is thinned, and thereafter at 5-year intervals. During the first thinning the lower branches of the trees that are left are lopped off to a height sufficient to insure a clean bole for turpentining during subsequent years. The wood and resin rights are sold for a period of five years, the turpentining being done by the purchaser, who, at the end of the operation, fells those trees marked for thinning.

The wood is used for mine timbers, boxes, crossties, telegraph poles, etc. Turpentined timber is preferred over unturpentined, since it is very resinous and so resists decay for a longer time. The last thinning is made when the trees are about 30 years old, and the remaining pines, numbering about 50 per acre, are then turpentined. At the end of the rotation period, owing to various casualties, there remain only about 30 trees per acre for lumbering.

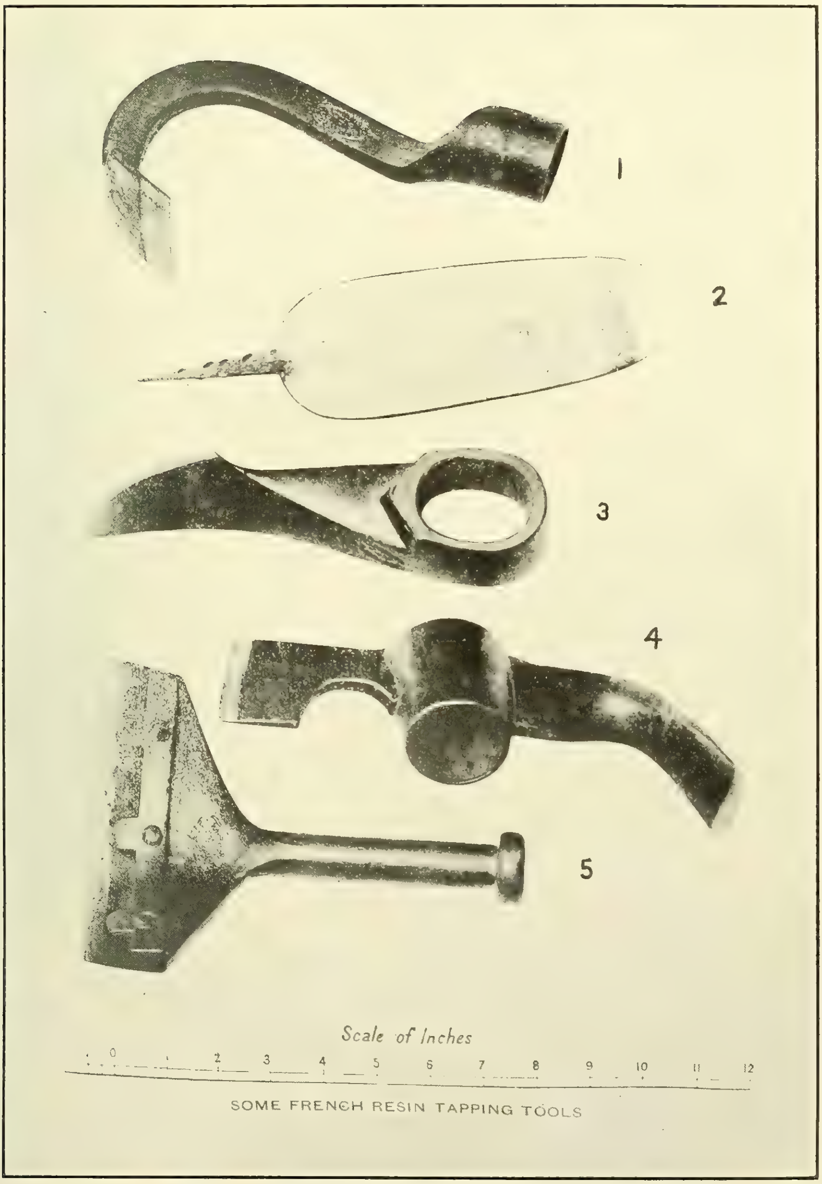
Up to the year 1860, practically all resin was collected in holes scooped out of the sand at the base of the trees. This method was wasteful, and the gum was badly contaminated with sand and other débris. The use of an earthen pot with a gutter was suggested in 1840 by M. Hugues, of Tarnos, but was not taken up until 1860. At present the Hugues cup and gutter system has almost entirely superseded the old method.

BARKING.

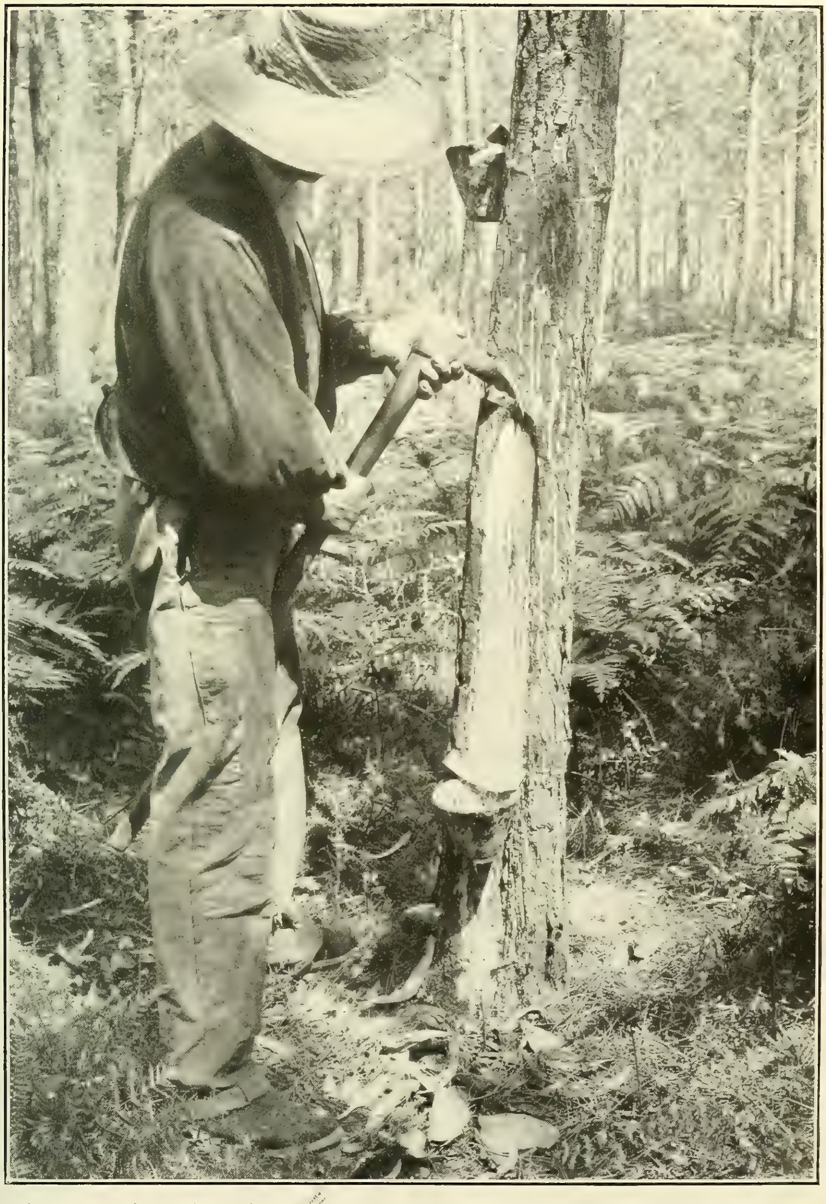
Before the turpentining season opens the outer bark is removed over an area exceeding somewhat the area to be chipped during the coming season. The denuded area measures 24 inches in height and 6 to 8 inches in width, and in depth reaches to the living layer of the bark. The operation is performed carefully with a wide-bladed ax. Above the height of a man the ax is replaced by a tool with a hook-shaped blade, 3 inches wide, attached to a long handle, which is wielded with a pulling motion. The bark is removed to prevent dulling the delicate edge of the chipping tools, and the rays of the sun on the exposed area are supposed to have a beneficial effect in stimulating the flow of resin.

HANGING CUPS (HUGUES SYSTEM).

The face is opened the first of March by removing a chip 1.6 inches high, 3.5 inches wide, and 0.4 inch deep from near the base of the tree. The tool used is a peculiarly shaped instrument called the "abschot" (Plate IX–3). A zinc gutter is inserted at the base of the wound in a



FRENCH TURPENTINE TOOLS.



CHIPPING A LOW FACE, SHOWING THE SHAPE OF THE AXE AND RELATIVE SIZE OF THE FACE.

CHIPPING A HIGH FACE, SHOWING THE PRACTICE OF INSERTING CHIPS ON SIDES OF FACE ON LEANING TREES TO GUIDE GUM INTO CUP.

gash made by a chisel (Plate IX–5) with a cutting edge in the shape of the arc of a circle. Below the cutting edge is a socket into which the gutter fits. The gutters are 8 inches long and 2 inches wide, and in some cases are provided with five teeth. A gash 0.2 inch deep has been found sufficient to hold the gutters, since the resin soon enters the wound and acts as a cement.

The pots used are made of glazed earthenware, conical in shape, 4½ inches wide at the top, 3 inches at the bottom, 6 inches high, with a capacity of about 1 quart (1 liter). The cup rests on the ground the first year, and is raised along with the gutter at the beginning of each succeeding year of operation. The upper part of the pot is held in place by the gutter, which projects out and downward, while the base rests on a nail driven into the tree. The top of the cup is never provided with a hole for hanging on a nail.

CHIPPING.

Chipping is begun about the first of March and ends the latter part of October. A total of 40 chippings is usually made in one season.

The chipping tool (abschot) is of two types: One type is a combined adz and gouge, the blade hanging at right angles to the handle, its edge shaped like the arc of a circle. In the other type the blade is parallel to the handle, but bent outward so that the cutting edge does not fall within the plane of the handle.

In using the abschot the workman stands to one side and in front of the face, with the handle between his legs (Plate X). In removing the chip the blade is inserted at the extreme upper corner of the face and is drawn diagonally toward the workman. Little effort but great skill is required.

The wood removed in chipping is in the form of shavings, so that the edges of the face are perfectly smooth, allowing the wound to heal rapidly. The face increases in height about 0.6 inch at each chipping. After the face is opened, chipping is repeated every 8 days from March to May, every 5 days from June to the end of August, and every 8 days from September to the middle of October or the first of November.

After the face has reached the height of a man the abschot is discarded for the rasclet. The rasclet (Plate IX–4) has a hook-shaped blade, with its edge at right angles to the long handle, and the chip is removed by a pulling motion. In the case of leaning pines, wooden chips are inserted along the edge of the face to guide the resin toward the pot (Plate XI).

The dimensions of the faces must conform to the tapping specification, and frequent inspection is made by government officials to see that these are carried out. Since the wages of the workman consist of half the proceeds from the sale of the resin, he naturally wishes to collect as much resin as possible, and is tempted to increase the size

of the face beyond the prescribed limits. An instrument devised by Demorlaine in 1898, called the "facemeter" (quarrimetre), permits of a ready and accurate measurement of the face.

SYSTEMS OF TURPENTINING.

Two systems of turpentining are employed, "gemmage a vie" and "gemmage a mort." "Gemmage a vie" is the system used when the tree is to be moderately turpentined for a long period of years; "gemmage a mort" when the trees marked for thinning or final felling are to be made to yield the greatest possible amount of resin in five years without actually being killed.

The following articles are taken from the turpentining specifications issued by the French Government in 1909:

Gemmage a vie.—The tapping will take place on either one or two faces, according to the indications of the Service des Eaux et Forets. Only those trees can be tapped with two faces which have been designated for this purpose.

The faces will be started above the swelling of the root and raised either vertically or in accordance with the grain of the wood.

If the tapping period is for five years, the face can be raised 0.60 m. (24 inches) during the first year and 0.65 m. (26 inches) during the following years in such a manner that the total height does not exceed 3.2 m. (10 feet 6 inches).

If the tapping period is for four years the face can be raised 0.60 m. (24 inches) during the first year; 0.65 m. (26 inches) during the second; 0.85 (33 inches) during the third, and 1 m. (3 feet 3 inches), in such a manner that the total height does not exceed 3.1 m. (10 feet 2 inches).

In every case the width of the faces should not exceed 0.09 m. (3.5 inches) the first year, 0.08 m. (3.1 inches) the second, 0.07 m. (2.8 inches) the third, and 0.06 m. (2.4 inches) at the beginning of the fourth.

The decrease in width should take place progressively in such a manner that the width of the face at the end of one year shall be that at the beginning of the year following.

The depth should not exceed 0.01 m. (0.4 inch), the measure being taken under a cord stretched from one border of the face to the other, at the beginning of the red part of the bark.

The tapping will take place according to the directions of the Service des Eaux et Forets; either by fours (au quart), the faces up to the fourth inclusive being made, as far as possible, two by two at the extremities of the same diameter; or by threes (au tiers), the faces up to the third inclusive being made by dividing the circumference of the tree into three nearly equal parts; the second should be opened at the right of the first when facing the latter.

In case of the absence of directions in the contract the tapping will be done by fours.

Gemmage a mort.—If the trees to be tapped *á mort* form part of the sale or are abandoned to the lessors, the latter can work them as they think best.

In the contrary case the lessors should not tap them in a manner to diminish the value which they should have as fuel and structural timber. The dimensions of the face should be such that its whole area never exceeds the limits of an ordinary face.

The tapping operation will be confined between March 1 and October 31 of each year, but the contractor can commence to bark the pines which are to be tapped and place the gutters February 1.

He can also collect the scrape up to December 1 of each year of the tapping period, except the last year, when this operation should be ended the 15th of November.

Two kinds of scrape are distinguished in France. The hardest kind adhering firmly to the face is called "barras," while the soft scrape is called "galipot." The tool used (Plate IX–1) for removing the scrape resembles that used in removing the outer bark, except that the blade is only 1½ inches wide. Usually the trees are scraped but once a season, in November, but sometimes an additional scraping is made in June.

The method of collecting the crude gum is practically identical with that used in America.[1] The resin is temporarily stored in wooden tanks sunk into the ground at convenient points in the forest until it is ready to be transported to the still.

FRENCH DISTILLATION METHODS.

In French operations the barrels of resin as they come from the forest are usually stored in large tanks, so as to form a reserve supply to be worked up during the winter months when no resin is collected. The storage tanks are sunk into the ground at a distance of 75 feet from the still, and the resin transferred to the latter by means of an overhead trolley. The tanks are built of brick or cement and covered with tile.

PURIFICATION OF THE RESIN.

The resin is often subjected to preliminary treatment previous to distillation to remove the trash. This is not done, however, unless high grade rosin can be produced which will bring a good price, since the process results in loss of turpentine and requires extra fuel and labor.

The preliminary treatment involves fusion, clarification, decantation, and straining. The fusion is performed in open or closed pans.

Open pans.—The resin is liquified in a cylindrical copper pan 6 feet in diameter and 1½ feet in depth, with a slightly concave bottom.

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[1] Comparison of yields of crude gum per inch of width of face, French and American methods:

Data from French operations indicate an average yield of 1.8 liters of crude gum per face per year, or 4 pounds.

If chipped 40 times yield per face per chipping=0.1 pound.
If face is 3.5 inches wide yield per inch width=0.029 pound.
If face is 4.0 inches wide yield per inch width=0.025 pound.

Data from American operations:

Crop A—8,000 faces. (See page 25):
206,235 pounds gum in 4 years=6.4 pounds per face per year.
43,633 pounds scrape in 4 years=1.4 pounds per face per year.

Total 7.8

If chipped 32 times yield per face per chipping=0.244 pound.
If face is 12 inches wide yield per inch width=0.020 pound.
If face is 14 inches wide yield per inch width=0.017 pound.

Crop D—8,000 faces. (See page 25):
279,260 pounds gum in 4 years=8.7 pounds per face per year.
53,915 pounds scrape in 4 years=1.7 pounds per face per year.

Total 10.4

If chipped 32 times yield per face per chipping=0.325 pound.
If face is 12 inches wide yield per inch width=0.027 pound.
If face is 14 inches wide yield per inch width=0.025 pound.

This pan, inclosed by brickwork and heated by the flames from a fire-box, has a capacity of about 325 gallons.

After the pan has been filled with crude resin the heating is conducted very slowly to prevent "burning." A workman stirs the mass constantly with a wooden paddle to render the heating uniform. When boiling begins the heating is discontinued, as the temperature should never be allowed to exceed 90° to 100° C. To clarify the mass the temperature is suddenly reduced by drawing the fire. Sometimes a small amount of water is thrown into the fire box and upon the bottom of the pan. If this delicate operation is successful, the mass will settle into several layers after standing for four or five hours. A layer of chips, bark, etc., will be found on the surface; then a layer of resin; and below this a layer of colored water with a deposit of sand, etc., on the bottom. The floating chips and bark are removed by skimming. The resin may then be run out through pipes arranged at different levels, but usually is dipped out. The heaviest material is filtered through a screen to remove the sand, the filtrate separating into a layer of colored water surmounted by a small amount of inferior resin. By this procedure a resin is obtained which on distillation will yield a rosin several grades higher than the original resin would give if distilled with all its impurities.

Purification in an open pan results in the loss of from 2 to 3 per cent of turpentine, and there is considerable danger of fire. Several pans provided with covers have been designed to overcome the objections cited.

Closed pans.—The pan designed by Dromart (fig. 6) illustrates the closed type. It is provided with a horizontal cover whose edge fits into the groove (R), the latter being fed by a stream of cold water so that the cover is hermetically sealed. The pan is charged without loss of turpentine by means of a box (B) with a trap in the bottom worked by a lever. By manipulating this lever the resin contained in the box falls into the pan. To obtain uniform heating the resin is stirred by means of an agitator (G). At the end of 4 to 5 hours the melted resin shows a temperature of from 85° to 90° C., and a jet of steam issues from a test hole in the cover. The heat is then reduced, and the liquid mass cooled by dumping in one or two boxes of resin through the trap. After stirring vigorously the mass is allowed to rest for 12 hours. The resin is then decanted through a pipe (V) situated above the bottom so as to keep the layer of water and dirt below its orifice.

It is sometimes difficult to separate the water and solid impurities from the resin, owing to the fact that the density of the resin and that of the water are so nearly the same. The density of a gum containing 80 per cent rosin and 20 per cent turpentine, at 20° C., is about 1.023, while at the same temperature distilled water has a density of 0.998. Since the water in the resin contains certain amounts

of dissolved matter, its density may be greater than the figure given, while the density of resin richer in turpentine will be less than 1.023. To separate the two it is necessary to lower the density of the resin or increase the density of the water. The former is accomplished by adding certain amounts of "heads" and "tails" from a previous distillation, and the latter by adding a cheap salt, such as common salt or soda.

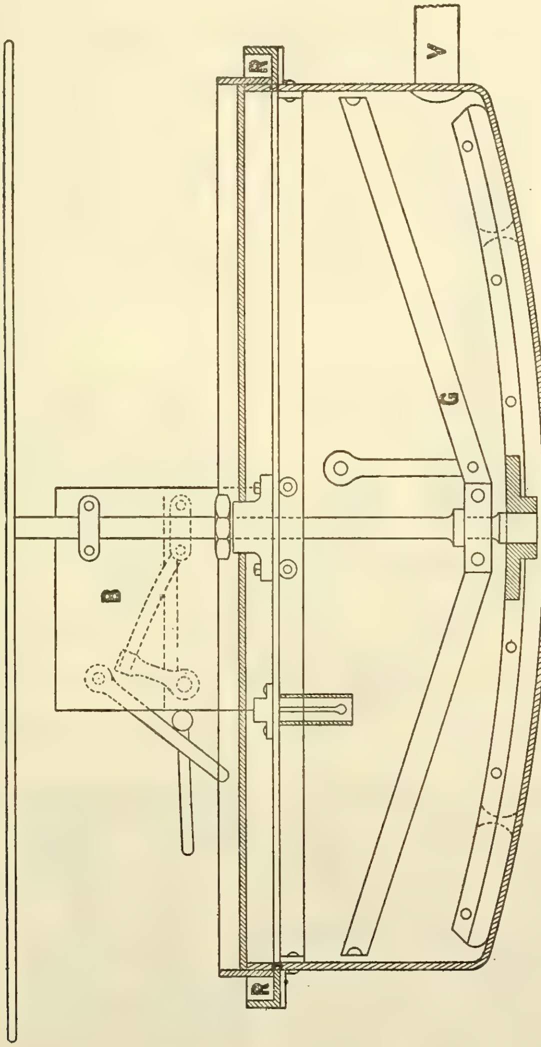

FIG. 6.—Tye of closed evaporating pan used in France to prevent loss of turpentine when gum is purified.

DISTILLATION BY DIRECT HEAT.

Direct heating is the method of distillation generally employed in France. The type of still and its method of operation are exactly the same as in the United States.

DISTILLATION BY STEAM.

Of the 200 stills producing turpentine and rosin in France, only about 30 use steam. Several types of steam apparatus are employed, but the Dorian still will serve as an example of the stills heated by steam only.

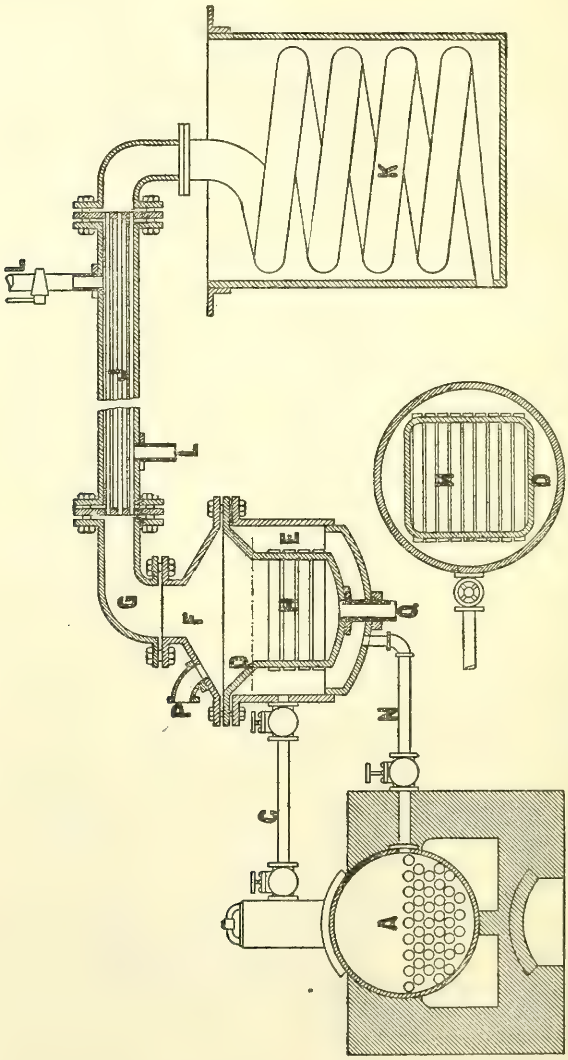

Fig. 7.—Type of steam turpentine still used in France.

This still is remarkable in its simplicity, compactness, and efficiency. Its principal advantage lies in the fuel economy obtained by returning directly to the boiler the condensed water obtained from the steam used in heating the still, instead of allowing it to flow away as a complete loss or running it into a tank for feeding the boilers.

The apparatus (fig. 7) consists of a steam generator, still, and condenser. The generator A, which may be of any type, feeds the

still by a pipe C attached to the steam dome. The still is constructed entirely of steel made to stand a pressure of 10 atmospheres, although 6 atmospheres is never exceeded in actual practice. The still consists of a gate valve P for introducing the crude resin and another gate valve Q for discharging the rosin; the body of still D, shaped like a prism; a steel jacket E, circular in shape; 32 tubes H, arranged crosswise in four series of eight tubes each, running through the still from one side to the other, through which passes steam from the jacket E; a hood F; a still-head G; and a pipe N, which leads back to the boiler the water produced by condensation of steam in the still. Since the pressure in the boiler and in the steam jacket is the same, this condensed water readily returns to the boiler by its own gravity.

The crude resin, divided into thin layers by the pipes H, distills rapidly. To carry the turpentine over, water is supplied through a funnel in the top of the hood F.

The condensing apparatus consists of a tubular condenser J and an ordinary worm K. The condenser is made up of a series of tubes from 10 to 12 feet long, riveted to two steel plates, and is fed with cold water through LL′. The tubular condenser is so efficient that the worm becomes almost useless.

A still having a capacity of 92 gallons (about 2 barrels) has a heating surface amounting to about 120 square feet, and permits the distillation of one charge in about 40 minutes.

When the turpentine is completely removed the introduction of water ceases. The heating is continued by means of the steam jacket until the rosin is free from water.

COMPARISON BETWEEN DIRECT AND STEAM HEATED STILLS.

The disadvantages of distilling with directly heated stills may be summarized as follows:

1. During the distillation of the crude resin the ligneous impurities may undergo a partial carbonization which colors the rosin.
2. The rosin becomes exceedingly dark at high temperatures.
3. The rosin may undergo incipient decomposition and color the turpentine more or less yellow.
4. Distillation by direct heat is a delicate operation, difficult to regulate, and requiring an experienced man. It can be applied only to a comparatively small quantity of material, if good results are to be obtained.
5. Increased fire risk.

By using stills heated by steam the above disadvantages are removed, but others are introduced. The reasons why the use of steam stills has not become general are:

1. Complicated apparatus.
2. Greatly increased cost of apparatus and expense of operation.
3. Necessity for a large stock of crude resin, if the still is to be operated economically.
4. With the majority of apparatus the crude resin must be given a preliminary treatment to remove chips, bark, sand, and other trash.

5. Only a slight increase in the commercial value of the turpentine and sometimes of the rosin.[1]

However, when fuel and crude resin are plentiful, steam stills have the following important advantages:

1. Very pure turpentine, better than that obtained by direct heat.
2. Rosin not superheated, and but slightly colored.
3. Simple and easy control of the distillation.
4. Decrease of fire risk.

As a general rule, an experienced distiller will obtain as good results with the ordinary American still as with a steam still.

THE SUPPLY OF LONGLEAF PINE FOR TURPENTINE OPERATIONS.

Up to the middle nineties the large supply of yellow pine stumpage, the prejudice against lumber cut from turpentined trees, and the lack of adequate transportation facilities in many regions where turpentine operations were conducted, caused large bodies of turpentined timber to be abandoned and left to be destroyed by fire, wind, and decay. It is estimated that in each of the States of North Carolina, South Carolina, Georgia, Florida, Alabama, and Mississippi the loss in boxed timber has amounted to from three to ten billion board feet.

At present the damage to standing timber due to turpentine operations has been considerably reduced. The cup systems lessen the fire risk and the heavy demand for lumber, coupled with improved transportation facilities, has shortened the period between the end of turpentine operations and the beginning of lumbering. However, as the supply of timber available for turpentining has grown smaller, the practice of turpentining undersized trees has become common, especially in second-growth stands that have come up after old lumber operations. When a tree under 6 inches in diameter is boxed it seldom makes further growth, and cupping has almost as bad an effect. Not only is further growth prevented, but the tree becomes a menace to the rest of the stand through windfall, fire, or decay. The future production of naval stores in the Southeast is rendered uncertain by the practice of turpentining small trees, and the future supply of longleaf pine is endangered. Moreover, the returns derived from turpentining small timber are, as a rule, hardly sufficient to cover the expense of operation.

The scarcity of longleaf pine suitable for turpentining has reached an acute stage in North Carolina, South Carolina, and Georgia, and is the natural result of the exhaustion of the virgin pine forests. While considerable "round" timber—that is, timber which has never been tapped—remains in Alabama, Mississippi, Louisiana, and Texas, it is

[1] On Apr. 5, 1911, the quotation at Savannah on "B" rosin, the lowest grade, was $8.15 per barrel, while "WW," or the highest grade, brought but $8.62 per barrel. The average price of "WW" rosin during the naval stores year 1913–14, was $6.38, and of "B" rosin, $3.96 per barrel.

for the most part held by large lumber syndicates, which usually are unwilling to permit turpentine operations. A few of the holding companies are beginning to permit turpentining, either carrying on the operations themselves or leasing the privileges to large naval stores companies. In Florida the small operator has more oppor-

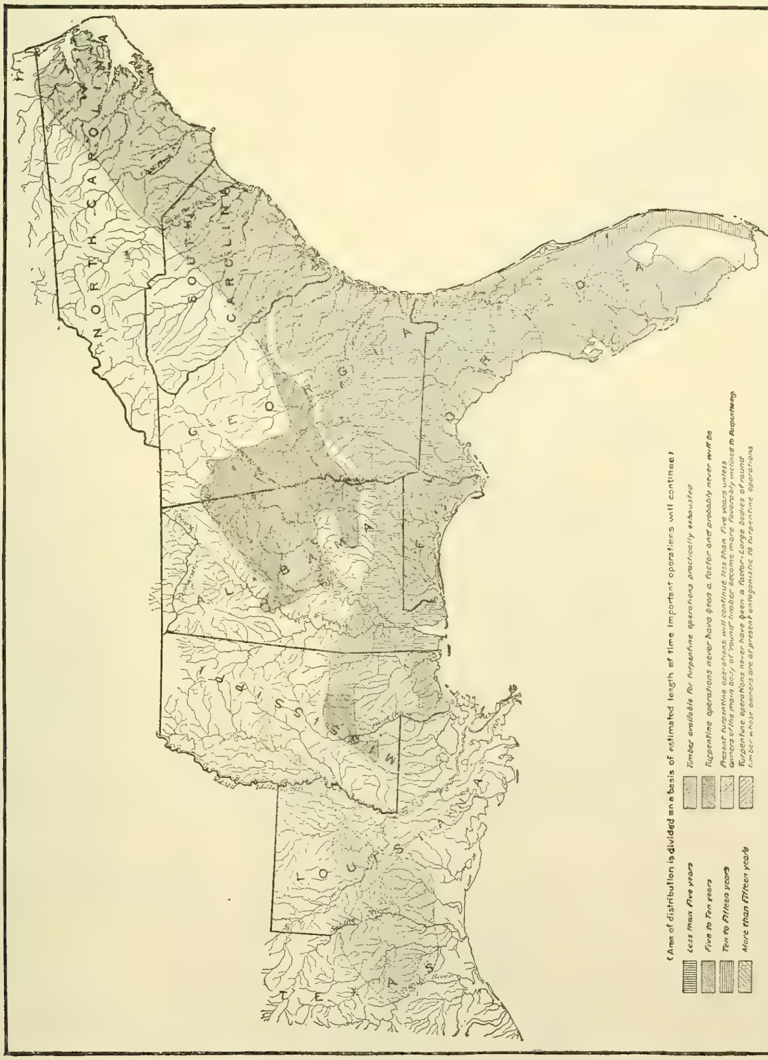

FIG. 8.—Approximate distribution of longleaf pine with reference to turpentine operations.

tunity, since much of the timber is at present in the hands of turpentine men.

Figure 8[1] shows the distribution of longleaf pine. The various styles of crosshatching denote the estimated number of years (from 1909) for which virgin timber will be available for turpentine opera-

[1] Taken from unpublished report, "Investigation of the Naval Stores Industry," by A. L. Brower and J. D. La Fontissee (1909).

tions. By this it is not meant that production will cease in any given region within the time indicated on the map, but that after the lapse of such time it is probable that the turpentine operator will have to make use of second-growth timber and that left by the lumberman. Under these conditions the production will amount to but a fraction of the present production. This prediction is based on the supply of

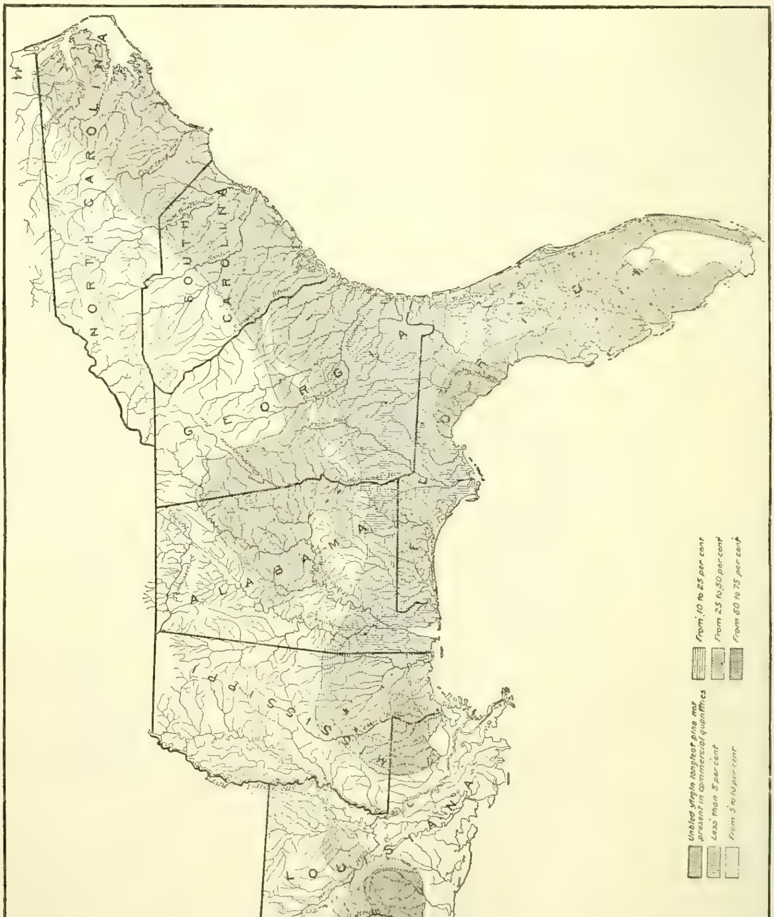

FIG. 9.—Approximate distribution of longleaf pine with reference to percentage of original stand remaining unbled.

longleaf, and does not take into account the possibility of utilizing loblolly and shortleaf pine as a source of naval stores.

Figure 9 [1] indicates the percentage of the original longleaf pine that still remained standing "round" in 1909. The data are not

[1] Taken from unpublished report, "Investigation of the Naval Stores Industry," by A. L. Brower and J. D. La Fontissee (1909).

intended to be accurate for any particular locality, but rather to represent as correctly as possible the conditions generally obtaining over the territory, the unit of consideration seldom being less than a county. The high price of naval stores in 1911 produced an unprecedented invasion of the "round" timber. It has been estimated that 75 per cent of the "round" timber held by turpentine operators was tapped in 1912.

YIELDS PER CROP IN VARIOUS STATES.

Table 16 shows the yield per crop in six States in the turpentine belt and the percentage of gum secured by boxing and cupping. It is noticeable that the States in which the yield per crop was largest also made the largest use of improved methods. The timber used in turpentine operations in Louisiana and Texas is, however, generally of larger size than in the other States mentioned, so that a somewhat larger yield per crop under the same conditions would be expected, although not such a difference as shown in Table 16.

TABLE 16.—*Average yields in turpentine operations, by States,[1] during 1909.*

State.	Yield of turpentine per crop.	Percentage of gum secured by cupping.	State.	Yield of turpentine per crop.	Percentage of gum secured by cupping.
	Barrels.			*Barrels.*	
Alabama	35.6	8	Louisiana	44.7	44
Florida	29.8	16	Mississippi	34.5	11
Georgia	26.5	9	Texas	43.5	49

[1] Taken from statistical report on naval stores by Brower and La Fontissee.

Table 17 shows the new crops started by the box and cup methods in 1909, 1908, and 1907. The figures indicate that the cup method is steadily gaining ground; they also show that North Carolina and South Carolina at present play very little part in the production of naval stores.

TABLE 17.—*New crops started by box and cup methods in 1909, 1908, and 1907.[1]*

State.	Crops—1909.			Crops—1908.			Crops—1907.		
	Boxed.	Cupped.	Per cent cupped.	Boxed.	Cupped.	Per cent cupped.	Boxed.	Cupped.	Per cent cupped.
Alabama	337	131	28.0	420	84	16.7	423	71	14.4
Florida	1,374	326	19.2	1,593	313	16.4	2,065	210	9.2
Georgia	1,026	120	10.5	1,182	101	7.9	1,482	139	8.6
Louisiana and Texas	92	135	59.5	163	113	40.9	97	67	40.9
Mississippi	181	90	33.2	252	49	16.3	288	40	12.2
North Carolina	6			15	1	6.3	3	1	25.0
South Carolina	42			41			91		

[1] Taken from census report for 1909, reported as virgin, yearling, and third-year faces worked in 1909. Later statistics are, unfortunately, not available.

POSSIBILITIES OF WESTERN PINES AS A SOURCE OF NAVAL STORES.

During 1911 and 1912 the Forest Service conducted experiments on western yellow pine in Arizona, on western yellow pine, Jeffrey pine, digger pine, singleleaf piñon, and lodgepole and sugar pine in California and northeastern Oregon, and western yellow pine and piñon pine in Colorado, to determine the quantity of crude gum which could be secured from these pines by the methods ordinarily employed in the turpentining of longleaf yellow pine in the Southeast.[1] The field work was supplemented by laboratory analyses to determine the quality of the gum.

Table 18 compares the yields obtained in Arizona with those obtained in experiments conducted on a commercial scale in Florida. The Arizona experiments show a yield from western yellow pine about four-fifths as great as that obtained from southern yellow pines on average operations in Florida in the same period of time. Weather conditions in Arizona, however, will allow only a 24, or possibly a 26-week season, as against 30 or 35 weeks in the Southeast, so that when the yields for the entire season are compared western yellow pine shows a production about two-thirds as great as that from southern yellow pine. The average proportions of rosin and turpentine in the gum were about the same in both regions, as was the composition of the turpentine.

TABLE 18.—*Comparison of yields, in pounds, of crude gum and scrape from western yellow pine in Arizona and longleaf pine in Florida.*

Locality.	Crop designation.	Total weight obtained during season.		Average per cup per week.	
		Dip.	Scrape.	Dip.	Scrape.
Arizona [1]	A	2,862.50	523.75	0.239	0.0436
Do	B	2,524.25	314.75	.210	.0262
Do	C	2,431.75	288.25	.203	.0240
Average		2,606.16	375.58	.217	.0313
Florida [2]	A	63,615.5	9,570	.256	.0386
Do	B	61,161.5	7,650	.246	.0308
Do	C	62,587	7,245	.252	.0292
Do	D	73,703.5	8,880	.297	.0358
Average		65,266.9	8,336	.263	.0336

[1] Each crop of 500 cups chipped 24 times. [2] Each crop of 8,000 cups chipped 31 times.

The California experiments on western yellow pine were carried on from July 7 to November 1, 1911, and from May 10 to August 3, 1912. The yields obtained in 1911 and 1912 are combined in Table 19, to show the flow for an entire but not a continuous season.

[1] The California and Oregon experiments were made under the direction of Mr. C. Stowell Smith and Mr. J. B. Knapp, assistant district foresters, districts 5 and 6. A complete report of this work is on file at the Forest Service, Washington, D. C., and at the Forest Products Laboratory, Madison, Wis. For a detailed description of the Arizona and Colorado experiments see Forest Service Bulletin 116, "Possibilities of Western Pines As a Source of Naval Stores," by H. S. Betts.

TABLE 19.—*Yields of California western yellow pine, by months (crop of 300 cups, chipped 28 times).*

Date of dipping.	Weight of dip.	Date of dipping.	Weight of dip.
1912.	*Pounds.*	1911.	*Pounds.*
May 10–11	175	August 16	217
May 23	153	September 5	189
June 6–7	146	September 15	129
June 21	156	Septemer 27	172
July 6	171	October 19	179
July 20	197	November 1	152
August 3	260	November 28	212
Total	1,258	Total	1,250
		Total for 1912 and 1911	2,508
		Average per cup per week	0.3

The average flow per cup per week in the California experiments for a season of 29 weeks was somewhat greater than in the Florida experiments recorded in Table 18 for the same period of time. The California yield is also slightly greater when the production for the entire season is compared.

The composition of the volatile oil obtained by distilling the gum from the California trees differs from that of ordinary turpentine somewhat more than does the Arizona turpentine, but the oil probably will be satisfactory for industrial purposes. The yield from western yellow pine in northeastern Oregon was very small compared with that in California. This can be attributed in part to the unusually adverse climatic conditions during the season, but it is not likely that more favorable weather conditions would increase the yield enough to make turpentining in that region a profitable industry.

Jeffrey pine in California yielded only 61.5 per cent as much as western yellow pine farther south during the same period. The principal constituent of the oleoresin from Jeffrey pine is heptane, which can not be used as turpentine, but has been employed to some extent for medical purposes. Digger, piñon, lodgepole pine, and sugar pine in California were found to yield such small amounts of oleoresin that it would be impracticable to tap them on a commercial scale unless the particular oil they produce could be made to bring a high price for some special purpose.

Piñon pine (*Pinus edulis*) in Colorado had a rate of flow slightly over one-half that of the Florida pines for a 20-weeks' period, from June 9 to October 31. The volatile oil from the piñon gum differs somewhat from ordinary turpentine, but is probably suited for industrial use.

PROBLEMS OF COMMERCIAL DEVELOPMENT.

In considering the possibilities of commercial turpentine operations on western pines the problem of labor is one of the first that presents itself. In Arizona the Mexicans, who constitute a large part of the laboring class, are totally unfamiliar with turpentine work. Negro turpentine hands could be brought in from the Southeast, but

their transportation would be costly. A few negro hands might be secured to teach the Mexicans, but whether the results would be satisfactory is, of course, unknown. In California both Indian and white labor is available in many timbered portions that have turpentine possibilities, but here also the chippers would have to be taught how to use a hack.

The shorter season in Arizona, as compared with that of the Southeast, and the comparative severity of the winters in the timbered parts of the State, might make it necessary to discontinue operations entirely for a few months during the winter. This would necessitate the reorganization of the operating force each spring, with a great many attendant difficulties. The flow continued longer in California than in Arizona, the experimental areas in the former State showing a considerably higher average temperature than those in the latter, though the diurnal range of temperature in California was greater.

Western yellow pine timber generally grows in open stands free from underbrush, and in most cases there would be little, if any, more difficulty in moving the crude gum than in the Southeast. On rough ground burro pack trains might be used. Two small kegs or buckets, holding about 150 pounds of dip, could be slung on each animal.

The number of cups that can be hung on an acre of average western yellow pine compares favorably with the number hung on many areas now being turpentined in the Southeast. The western trees are larger than most of the southeastern ones, though their bark is thicker and rougher, and the outer portion must be removed before the trees are chipped. This, of course, means the expense of an extra step not necessary in southeastern operations. Such work can be done by the use of a broadaxe or heavy spade-shaped tool with a cutting edge.

The cost of securing turpentine rights in the Southeast is constantly rising, and it is likely that turpentine stumpage could be leased at lower rates in the West. At present the turpentine and rosin used in the West is shipped from the Gulf States, and the advantage of cutting out a two or three thousand mile haul to western markets is evident.

The naval stores industry is not new in California. During the Civil War when the supply of naval stores from the South was cut off an attempt was made to supply the northern States from the Pacific coast. The industry remained active for four or five years, but suddenly declined when North Carolina again came into the market after the close of the war.

The commercial success of turpentine operations in the Southwest will be doubtful until tried on a commercial scale. Nearly as much turpentine and rosin were obtained from western yellow pine as from

longleaf, and the amount of timber available for turpentine operations in the Southeast is constantly diminishing. These two facts make it reasonable to suppose that turpentine operations in the large tracts of virgin pine timber of the West will in time be justified.

SPECIAL PROBLEMS INVESTIGATED—ARIZONA AND CALIFORNIA WESTERN YELLOW PINE.

EVAPORATION FROM CUPS.

The rate of evaporation from the cups in Arizona was determined by exposing cups half full of fresh gum to the action of the air and weighing them at regular intervals. The samples of gum were secured by taking small amounts from as many of the cups as necessary on the first or second day after a fresh streak had been put on. Two samples were taken from each area after each dipping. Since dip is collected every three or four weeks in commercial operations the loss in weight during the first four weeks is the significant figure in the evaporation tests. Forty-eight evaporation samples were used. Of these 14 showed no loss at all in weight for the first four weeks; the remaining 34 samples showed losses ranging from 1.5 to 10.5 per cent. The average loss in weight for all the samples was 3 per cent. The gum as exposed contained turpentine, rosin, water, and chips. The loss by evaporation was of course made up of turpentine and water. The average loss of turpentine by evaporation from the cups in the Arizona experiments was therefore less than 3 per cent. The average loss in six similar evaporation tests in California was 2.5 per cent. No evaporation figures are available for southeastern operations.

COMPARISON OF YIELDS FROM NORTH AND SOUTH FACES—ARIZONA.

The total yield for 50 cups on the north side of 50 trees from the first dipping on June 3 to the last dipping on November 3 was 242.6 pounds and for 50 cups on the south side of the same trees 266.2 pounds. These weights show a 9 per cent greater flow on the south side of the trees than on the north. Figure 10 shows the average yield per week for both the north and south faces of each of the 50 trees, arranged in order of the yields from the south faces. Twenty-seven south cups yielded more than the corresponding north cups, while 17 north cups showed an excess over the corresponding south cups. The remaining six trees had about the same flow for both cups. The diagram shows the tendency of faces on the same tree to give the same yields. Trees having an exceptionally good or exceptionally poor flow generally show it in both faces.

EFFECT OF TEMPERATURE ON WEEKLY YIELD OF GUM.

Figure 11 shows the average flow per cup for 50 trees for each week and the corresponding average temperature. With but few excep-

tions the flow increased or decreased with increase or decrease of temperature. The effect of cool weather in checking the flow is especially marked toward the end of the season.

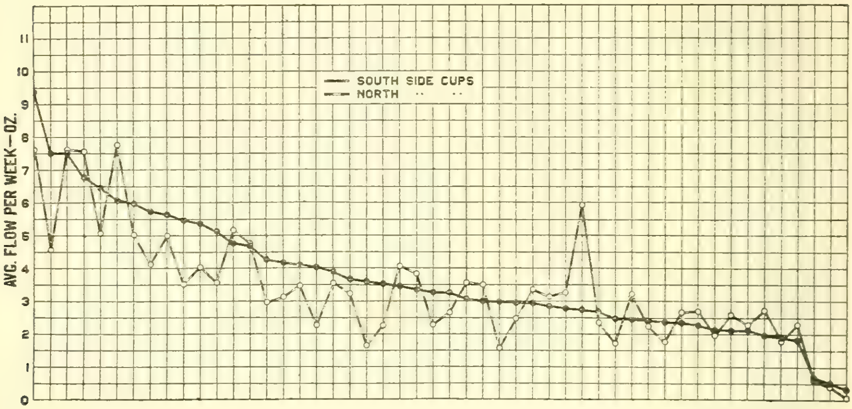

FIG. 10.—Comparison of flow from north and south faces of each of fifty trees.

RATE OF FLOW DURING WEEK.

Data on the variation in rate of flow were secured by weighing the north and south cups on 10 trees on the third day after each chipping throughout the season. The sum of the weights for each tree was compared with the weight of the total flow for the season from the

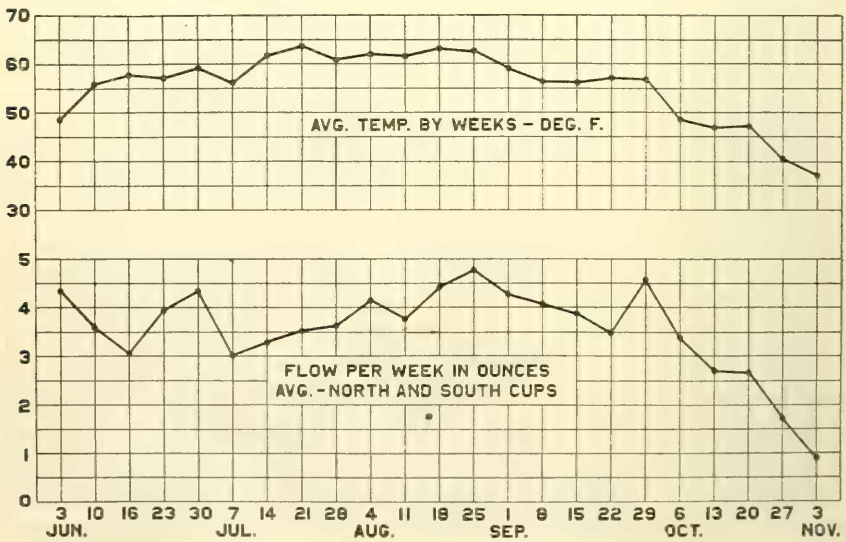

FIG. 11.—Relation between temperature and rate of flow of gum.

same trees. An average of the results shows that 73 per cent of the weekly flow occurred in the first three days. This ratio varied from 65 per cent to 78.6 per cent in the 10 test trees.

EFFECT OF VARYING FREQUENCY OF CHIPPING ON YIELD—CALIFORNIA.

Table 20 shows the yields obtained from three similar sets of 50 faces, each chipped at 3, 5, and 7 day intervals for the same period.

TABLE 20.—*Yields obtained by chipping at different intervals—California (50 faces in each set).*

3-day intervals.		5-day intervals.		7-day intervals.	
Date of chipping.	Weight of dip.	Date of chipping.	Weight of dip.	Date of chipping.	Weight of dip.
1912.	*Pounds.*	1912.	*Pounds.*	1912.	*Pounds.*
June 11	46	June 14	35½	June 13	25
June 23	49	June 29	47	June 27	31
July 5	66	July 14	49½	July 11	31
July 17	69	July 29	57	July 25	40
July 29	81	Aug. 8	45	Aug. 8	45½
Aug. 10	81				
Total	392		234		172½

Over twice as much gum was obtained by chipping at 3-day intervals as at 7-day intervals.

SUGGESTIONS FOR SPECIFICATIONS.

HANGING CUPS

1. The distance from the ground to the apex of the first streak shall not exceed 10 inches.

2. No "blazes" or similar scarification of the tree shall extend below the gutter or apron. The surface prepared for the placement of the gutters or aprons shall not extend beyond the ends of the same.

3. The peak of the first streak shall not be more than 2 inches above the gutter or apron.

4. The "streak" or gash made for the placement of the gutters or aprons shall not penetrate the wood of the tree more than one-half inch, the measurement to be taken from the dividing line between the wood and bark.

5. The gutters or aprons must be so attached that no "gum" flows between the tree and the gutters or aprons, or flows over the edge of same so as to fall without the cup or other receptacle.

6. For the first three years the cups and gutters shall be raised each spring to the top of the face worked the previous season.

7. A bar or strip of live bark not less than 4 inches wide in the narrowest place shall be left between the faces.

CHIPPING.

1. No tree under 10 inches in diameter shall be tapped. Minimum diameter of tree to carry one face, 10 inches; minimum diameter of tree to carry two faces, 16 inches; no tree shall carry more than two faces.

2. The face on trees from 10 to 16 inches in diameter shall not exceed 12 inches in width, and the faces on trees above 16 inches in diameter shall not exceed 14 inches in width.

3. The height of the face shall not be increased by more than 16 inches each year the tree is tapped.

4. Each streak shall not exceed a width of one-half inch or a depth of one-half inch, the depth being measured from the dividing line between the wood and the bark.

5. Before the chipping season opens the rough outer bark shall be scraped off over the entire surface to be chipped for each season, care being taken not to penetrate the living bark.

6. During the winter a space of at least 2½ feet shall be raked free of débris about each tapped tree.

PACKING NAVAL STORES.

Buyers and exporters frequently complain that turpentine and rosin barrels reach them in poor condition, unfit for further shipment. In order to improve the standards of naval stores packages, the Savannah Board of Trade in 1911 issued letters of instruction to naval stores operators as follows:

Turpentine barrels.—All barrels, whether new or secondhand, should be kept absolutely protected from the elements, and not allowed to remain subject to rain and sunshine at way stations and river landings. Glue will not take on damp staves. Every barrel should be glued twice before being filled. Use only the best quality of glue, as it is the cheapest in the end. Before gluing, see that your pot is absolutely clean. Put into this 20 pounds of good glue and 5 gallons of water, and allow same to soak overnight. On the following morning apply sufficient heat to melt up to a temperature not exceeding 160° F. Under no condition whatever must glue be allowed to boil, as this causes decomposition to set in, which causes the bad smell usually noticed around glue sheds, and renders it utterly worthless. This amount of prepared glue will be sufficient for 20 barrels. After gluing, barrels should be taken off the trough and stood on the head for about one-half hour, after which time they should be reversed, so that the surplus glue will run down equally on both heads. The barrels should then be well and thoroughly driven, and after standing for 24 hours should be given a second coat of glue, using the exact formula as before. They are then ready to be filled in 48 hours, and if treated in this way there should be no turning except for broken staves.

Rosin.—Rule No. 9 of the Savannah Board of Trade says in part: "Rosin barrels to be in merchantable order must have two good heads, not exceeding 1½ inches in thickness, staves not to exceed 1 inch in thickness; the top well lined." Too much stress, therefore, can not be placed on the absolute necessity of carrying out this rule to the very letter, especially regarding the thickness of staves and heading, for rule No. 10 specifically instructs the inspector to make a proper deduction in weight on all rosin when the staves and headings are more than the prescribed thickness in rule No. 9. In such cases, therefore, the operator will lose, as in addition to having the deductions made, for which he receives nothing, he must pay the full amount of freight to the railroad. Operators must see that every barrel is well coopered before shipment; see that all four hoops are nailed on the barrels, and the heads cut to fit close, and a good lining hoop as prescribed by rule No. 9 is in place. Staves must be properly equalized. Staves should be 40 inches long, and barrels built on a 22-inch stress hoop, which gives a well-shaped and easily handled barrel.

EFFECT OF TEMPERATURE ON VOLUME OF TURPENTINE.

Operators often complain that the factor's gauge of their barrels is 1 or 2 gallons less than their own. When the barrel has not leaked, the difference is usually due to the temperature at which the turpentine was placed in the barrel. Very frequently the turpentine is at a temperature of from 50° to 60° C. (from 122° to 140° F.) when the barrels are filled, and later cools to, say, 25° C. The mean coefficient of expansion of turpentine between 10° and 40° C. is 0.000817 per degree.[1] By rough calculation, assuming a specific gravity of 0.8500 at 50° C., if the original 50 gallons have cooled 25 degrees, the loss of volume by contraction will be about 1.2 gallons.[2]

When the condenser is incapable of cooling the distillate to ordinary temperatures, the barrels after being filled with the warm turpentine should be loosely plugged and allowed to stand several hours, or until their contents have cooled to the temperature of the surrounding atmosphere. The barrels may then be filled up to the required volume.

COST ESTIMATES ON A 20-CROP TURPENTINE OPERATION.

The cost figures which follow do not apply to any single locality; they have been derived from several sources, and are believed to cover a fair range.

The yields [3] have been calculated from the data contained in Forest Service Bulletin 90. The dip is assumed to contain 15 per cent water and trash and 18.5 per cent turpentine, and the scrape 10 per cent trash and 11 per cent turpentine; while 1 gallon of turpentine is assumed to weigh 7.25 pounds.

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[1] Technologic Paper No. 9, Bureau of Standards, 1912.

[2] The following formula will give the expansion or contraction of turpentine due to temperature changes

$$V' = \frac{GV}{G \pm (T' - T)\,.000817}$$

where G and V are the specific gravity and volume at the temperature T, and V' is the volume at the lower temperature T'.

[3] YIELDS PER CROP, CALCULATED FROM FOREST SERVICE BULLETIN 90.

First year—31 chippings:
- 83,495 lbs. dip, yielding 42. 8 bbls. turpentine and 199. 0 bbls. rosin.
- 12,560 lbs. scrape, yielding 3. 8 bbls. turpentine and 35. 4 bbls. rosin.

Total yield......... 46. 6 bbls. turpentine and 234. 4 bbls. rosin.

Second year—30 chippings:
- 74,791 lbs. dip, yielding 38. 2 bbls. turpentine and 178. 0 bbls. rosin.
- 14,818 lbs. scrape, yielding 4. 5 bbls. turpentine and 41. 8 bbls. rosin.

Total yield......... 42. 7 bbls. turpentine and 219. 8 bbls. rosin.

Third year—29 chippings:
- 57,324 lbs. dip, yielding 29. 3 bbls. turpentine and 136. 1 bbls. rosin.
- 13,399 lbs. scrape, yielding 3. 6 bbls. turpentine and 38. 3 bbls. rosin.

Total yield......... 32. 9 bbls. turpentine and 174. 4 bbls. rosin.

Fourth year—30 chippings:
- 45,100 lbs. dip, yielding 23. 0 bbls. turpentine and 107. 1 bbls. rosin.
- 19,908 lbs. scrape, yielding 6. 0 bbls. turpentine and 56. 2 bbls. rosin.

Total yield......... 29. 0 bbls. turpentine and 163. 3 bbls. rosin.

COST OF EQUIPMENT FOR A 20-CROP OPERATION.

1 25-barrel still, with shed and fixtures complete	$1, 200. 00 to	$1, 250. 00
20 shanties, at $50 to $75 each	1, 000. 00 to	1, 500. 00
2 houses, at $225 to $300 each	450. 00 to	600. 00
1 commissary	200. 00 to	225. 00
Sheds and stables	175. 00 to	200. 00
Tools	100. 00 to	125. 00
170 to 200 dip barrels, at $2.50 each	425. 00 to	500. 00
8 mules, at $200 to $250 each	1, 600. 00 to	2, 000. 00
4 wagons and harness, at $75 to $80	300. 00 to	320. 00
2 horses and saddles for woodsmen, $150 to $175	300. 00 to	350. 00
1 buggy and harness	75. 00 to	80. 00
Cups and gutters for 20 crops, at $45 to $55 per thousand	9, 450. 00 to	11, 550. 00
	15, 275. 00 to	18, 700. 00

COST OF OPERATION AND MAINTENANCE OF ONE CROP FOR ONE SEASON OF 30 WEEKS.

Hanging cups	$100. 00 to	$125. 00
Raking and burning	25. 00 to	28. 00
Chipping	277. 00 to	300. 00
Dipping	120. 00 to	150. 00
Scraping	25. 00 to	35. 00
Hauling dip and scrape to still	80. 00 to	110. 00
Distilling	45. 00 to	50. 00
Salary of woods rider	70. 00 to	75. 00
Salary of manager	50. 00 to	100. 00
Recruiting	10. 00 to	30. 00
Taxes and still license	15. 00 to	20. 00
Cotton batting, straining wire, oil, tools, etc	8. 00 to	10. 00
Depreciation on cups and gutters [1]	80. 00 to	95. 00
Depreciation on dip barrels	5. 00 to	6. 00
Depreciation on other equipment, at 10 per cent	27. 00 to	33. 00
Interest on total investment, at 8 per cent	60. 00 to	75. 00
Lease on timber, at $25 to $33 per 1,000 cups	262. 50 to	346. 50
	1, 259. 50 to	1, 588. 50

COST OF MARKETING ONE CROP.

Barrels and cooperage	$175. 00 to	$200. 00
Haul to shipping point	10. 00 to	100. 00
Selling commission, 2½ per cent	30. 00 to	35. 00
Inspection	8. 00 to	10. 00
Storage	5. 00 to	10. 00
Insurance, ½ per cent	6. 00 to	7. 00
	234. 00 to	362. 00

Cost of operation and maintenance of one crop	1, 259. 50 to	1, 588. 50
Cost of marketing one crop	234. 00 to	362. 00
Total cost for 1 crop	1, 493. 50	1, 950. 50
Cost for 20 crops	29, 870. 00 to	39, 010. 00

[1] The life of the cups and gutters is about 6 years.

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LOGAN WALLER PAGE, Director

Washington, D. C. ▼ July 14, 1915.

OIL-MIXED PORTLAND CEMENT CONCRETE.

By LOGAN WALLER PAGE, *Director, Office of Public Roads.*

INTRODUCTION.

The enormous growth of the American Portland cement industry, with its production of 22,342,973 barrels of cement in 1903 and 92,949,102[1] barrels in 1913, is striking evidence of the widespread use of this deservedly popular material of construction. Combined with sand and stone or gravel in the correct proportions and mixed with the proper amount of water, the resultant product—concrete—is a structural material of perhaps more universal adaptation than any other material now in use. Its application to foundations for heavy machinery, to dams, walls, bridge piers, tunnels, subways, and building blocks is well known. When properly reinforced with steel, its use is even more widely extended to the construction of bridges, vats, sewers, water conduits, and numerous other classes of construction.

The farmer has found concrete to be of material benefit to him in building various farm structures which were formerly made of more perishable materials. Thus, when reinforced with steel wire or rods, fence posts may be made with an interminable life and at very low cost. It is also exceedingly well adapted to the construction of water tanks, cisterns, silos, pavements, floors, buildings, feeding troughs, etc. Simplicity and ease of manufacture and of manipulation in construction work, great strength and durability, and comparatively low cost are some of the considerations which render its application so universal.

In spite, however, of the many virtues possessed by concrete as a material of construction, faults are apparent in its tendency to crack, owing to external temperature changes, to the rise and subsequent fall of internal temperature while it is hardening, and to the shrinkage which accompanies the drying out of the mass. Then, too, as ordinarily made, concrete is more or less porous and absorbent of moisture—characteristics of the material which are plainly evident in the damp appearance of concrete houses after a period of wet weather, in leaky basement walls and floors, and in reservoirs which persist in losing water.

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[1] Figures supplied by U. S. Geological Survey.

NOTE.—This bulletin is a revision of Bulletin 46, Office of Public Roads, and is of interest to those using moisture-proof cement concrete.

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If concrete could be made less absorbent of moisture and less porous, its ability to withstand the penetration of water would be greatly increased, and the material would then be a much more desirable one for structures in which it is now used with only partial success.

OIL-MIXED CONCRETE.

While experimenting in the Office of Public Roads in an attempt to develop a nonabsorbent, resilient, and dustless road material, one capable of withstanding the severe shearing and raveling action of automobile traffic, the writer's investigations led him into a very promising discovery. He found that when a heavy mineral residual oil was mixed with Portland cement paste it entirely disappeared in the mixture, and, furthermore, did not separate from the other ingredients after the cement had become hard. The possibilities of oil-cement mixtures for waterproofing purposes were recognized, and extensive laboratory tests were immediately begun to determine the physical properties of concrete and mortar containing various quantities of oil admixtures.

These tests have now extended over a period of considerably more than two years. Many valuable data have been obtained, through both laboratory and service tests, which demonstrate very definitely the worth of oil-mixed concrete in damp-proof and waterproof structures. Detailed results of these various tests are given in the appendix. The conclusions so far reached may be summarized briefly as follows:

It has been shown that the admixture of oil is not detrimental to the tensile strength of mortar composed of 1 part cement and 3 parts sand when the oil added does not exceed 10 per cent of the weight of the cement used. The compressive strength of mortar and of concrete suffers slightly with the addition of oil, although when not to exceed 10 per cent of oil is added the decrease in strength is not serious. Concrete mixed with oil requires a period of time from 50 to 100 per cent longer to set hard than does plain concrete, but the increase in strength is nearly as rapid in the oil-mixed material as in the plain concrete.

Concrete and mortar containing oil admixtures are almost perfectly nonabsorbent of water and are therefore excellent materials to use in damp-proof construction. The addition of oil, however, does not appear to increase to any great extent the impermeability of concrete subjected to heavy water pressure, and this method alone will probably not make the concrete proof against the actual percolation of water through the mass. It has been found that strict attention to the details of proportioning, mixing, and placing concrete accomplishes more toward making it waterproof or impermeable than the addition of any extraneous material. On the other hand, no amount of care in connection with the preparation of concrete prevents the

absorption of water into the mass. The addition of some water-repellent compound appears absolutely necessary to insure this result, and for this purpose laboratory tests have shown these oils to be at least equal to any other substance that has been used. Laboratory tests show that oil-mixed concrete is just as tough and stiff as plain concrete, and, furthermore, its elastic behavior within working limits of stress is identical with that of plain concrete.

The bond between concrete and plain-bar reinforcement is decreased by the use of oil in the concrete, but when deformed bars, wire mesh, or expanded metal is used there is no apparent decrease in the bond.

With the view of determining what effect the addition of oil to cement mortar would have in retarding the action of alkali salts on the cement, a series of experiments was conducted which seemed to indicate that the action of the salt solution is materially retarded by the addition of 5 to 10 per cent of oil to a 1:3 mixture. Plate I shows a view of a series of briquettes subjected for one year to the action of a 10 per cent solution of sodium sulphate. The briquettes in the upper row contained 10 per cent of oil; those in the middle row, 5 per cent of oil; and those in the bottom row, no oil.

SERVICE TESTS.

Two bridge surfaces of oil-mixed concrete were laid during April and May, 1910, in the borough of Richmond, New York City. About 400 feet of street were surfaced in 1910 in the city of Washington. Likewise, in the suburbs of Harrisburg, Pa., about one-half mile of roadway was laid with a 10 per cent oil mixture. Sections of roadway containing oil have also been laid on Hillside Avenue, Jamaica, N. Y., and at Chevy Chase, Md. Observations to date show that no apparent advantage has been gained in these particular cases by the addition of oil.

Service tests of oil-mixed concrete used as a damp-proofing material have also been made. A vault 112 feet long by 18 feet wide in the United States Treasury Building was constructed in the fall of 1910. (Pls. II and III.) The side walls of this vault contain 10 per cent of oil based on the weight of cement in the mixture. The roof was constructed of ordinary reinforced concrete with about 3 inches of 10 per cent oil-mixed concrete placed on top. For months the roof of this vault was subjected to several feet head of water without showing any signs of leakage. Another vault in the north end of the Treasury, on account of leaking, had never been available for storing anything of value. Oil-mixed concrete was placed on the roof of this vault and it is perfectly dry at the present time. Numerous floors of the subbasement of the Treasury Building and in the new Bureau of Engraving and Printing, and a floor in the Office of Public Roads, have been constructed with oil-mixed concrete and have remained entirely free from dampness up to the present time.

Several tanks constructed of oil-mixed concrete in the testing laboratory of the Office of Public Roads have remained absolutely water-tight since their completion over a year ago. One of these tanks was made of a mixture of concrete composed of 1 part of cement, 2 parts of sand, and 4 parts of stone, mixed with 10 per cent of oil based on the weight of cement in the mixture. It is used for storing concrete test specimens and is 14 feet long by 5 feet wide by 4½ feet deep. The bottom of this tank is 4 inches thick and is deposited on the cement floor of the laboratory. The sides are 6 inches in thickness and are reinforced with one-half inch deformed steel bars. A second tank was built very successfully merely by plastering oil-mixed Portland cement mortar against one-half inch mesh expanded metal. Although the sides and bottom of this tank are but 1 inch thick, it is absolutely water-tight against about 2 feet of head.

A number of firms, corporations, and individuals applied to the Office of Public Roads for information in regard to using this oil-cement concrete in various structures. In these cases the office supplied the oil specifications and directions for mixing and applying the materials, but no supervision. Later, inquiries were made relative to the success met with where the specifications had been followed. Many of these inquiries were not answered, but of the 29 replies received from persons who had used the oil-cement concrete, only 3 were wholly unfavorable, while 1 was partly so. Of the 3 unfavorable replies, 1 referred to the use of the material for paving blocks, and another to its use in the construction of tanks for holding acids.

A summary of these 29 replies is given in Table 1. As considerable difficulty was encountered in securing oils that met the specifications, substitute oils were used in some instances.

TABLE 1.—*Results obtained in the use of oil concrete as a waterproofing material in actual service.*

RESULTS FAVORABLE.

Reply No.	Nature of work.	Per cent oil used.	Proportions and consistency.	Character of workmanship.	Character of waterproofing required and results obtained.
1C	Lemon washing tank; floor for toilet; plaster partitions on metal lath.	5	....	Expert......	Results satisfactory in every way.
2C	Retaining wall............	10	1:3:5 (wet)..	.....do.......	Waterproof interior against damp earth. Results generally satisfactory.
3A	1½-inch finish on exposed floor over water tank.	1 gallon to bag cement.	Bag cement to 4 barrows sand.	.....do.......	To waterproof floor against percolation of rain water. Results good. Oil cement laid twice as fast as that without oil.
4A	Swimming pool, 20-inch wall, originally waterproofed with "Ceresit." Unsatisfactory (5 feet water in tank).	...do......	.....do.......	.....do.......	Scratch coat ½ inch thick plastered on inside of tank. Tile laid on this. Over 2 years old and has never leaked. Tile adhered well.
5B	Roof of tool house and silo..	10	1:6	Not expert..	Plastered 1 inch on metal lath. Results very good.
6B	Cellar of dwelling house....	¾ gallon to bag.	1:2:2	Not expert..	1 foot water in cellar before waterproofing. Absolutely water-tight after using oil concrete.

TABLE 1.—*Results obtained in the use of oil concrete as a waterproofing material in actual service*—Continued.

RESULTS FAVORABLE—Continued.

Reply No.	Nature of work.	Per cent oil used.	Proportions and consistency.	Character of workmanship.	Character of waterproofing required and results obtained.
7A	Cellar walls and floor 21 by 43 by 5 feet; walls 18 inches.	10	1:2:4	Expert	To waterproof against supersaturated earth filling. Excellent results. Feels assured as to value of oil for this class of work.
8A	Rain-water cistern 18 inches under ground; 15 by 15 by 10 feet; 14-inch walls.		1:3:5		Probably tight. No water comes into cellar 6 feet distant.
9A	Water tank—inside walls lined with mortar containing hydrated lime and "Aquabar."	10	1:3:3	Expert	Oil appears to be beneficial.
10A	Water tanks of various sizes and floors.	5	1:2	do	Oil mortar used to plaster inside of tanks. Results satisfactory. Floors satisfactory. Dry up quickly after flushing. Mortar "works" much better than plain.
11A	Floor of machine shop 12 by 15 feet; 2-inch top.	5	1:2	do	Construction recent, but apparently satisfactory.
12B	Floor in corn bin; and a poultry house complete (floor, walls, roof).	5	1:3 20 per cent hyd. lime.	Not expert	Roof tight except at one place where crack formed. Results good. Recommends use of oil.
13B	Walls and floor of hog house	5	1:2	do	Damp-proofing desired. Great success.
14B	Foundations (8 inches thick) and cistern (12 feet deep).	5	1:3:4 (wet)	Moderately expert.	Walls are perfectly damp-proof.
15B	Floor of grain bins	15	1:1 (wet)	Not expert	Is perfectly hard and waterproof.
16B	Paving block 12 by 14 by 5 feet; oil mixture used as facing.	2	1:3 (very wet).	do	Makes hard, very smooth surface, impervious to moisture because nonporous.
17A	Concrete silos	5	1:2½:4½ 1:2:4 (wet).	Expert	Results generally satisfactory.
18B	Concrete arch; facing of soffit.	10	1:2	do	Waterproofed concrete in excellent condition. Nonwaterproofed concrete badly disintegrated.
19B	Plaster coat to inside of cistern ½ inch.	10	1:4 (wet)	do	Waterproofing seemingly perfect. No known deterioration.
20B	Renovating leaky cistern; $\frac{1}{16}$ inch coat followed by brush coat.	20	Neat	Not expert	Results very satisfactory. Absolutely waterproof.
21B	Cellar wall, ¼-inch plaster coat.	8	2:3 (wet)	do	Wall so far waterproof.
22B	Basement walls of a building subject to action of ground water.	2	1:1:3		Absolutely waterproof and damp-proof. Stone wall above continually admits water.
23B	Tank for wood pulp	(1)	(1)	(1)	Results entirely satisfactory.
24A	Lining a cellar wall, subjected to 4 feet head of water; wall 6 inches thick.	10	1:2:4 (wet)	Expert	Only trouble slight sweating through joints.
25A	Vault walls, basement floor, freight elevator pit.	6	1:3:4	Moderately expert.	Wall sustains weight of street, is waterproof and very satisfactory. No other method of damp-proofing so thorough and satisfactory; none so inexpensive.

RESULTS UNFAVORABLE.

Reply No.	Nature of work.	Per cent oil used.	Proportions and consistency.	Character of workmanship.	Character of waterproofing required and results obtained.
1B	Cement blocks for track paving.	10	1:2:4 (wet)		Not successful. Blocks never used. Oil was added for toughness.
2B	Tank to hold 1 per cent soluble sulphuric acid at 150° F.	(2)	(2)		Not successful. Acid dissolved concrete.
3B	Floor of cellar 2-inch top	6	1:3 (very wet).	Expert	Has as much water as before coating was applied.
4	Cellar ½ inch thick	(1)	(1)	Not expert	Keeps about one-half volume of water out of cellar.

[1] Used according to specifications. [2] No data kept.

A very interesting experiment showing the nonabsorbent and nonpermeable character of oil-mixed mortar when subjected to low pressure is incompletely shown in Plate IV. Four mortar receptacles, 8 inches in outside diameter, 2½ inches high, and with walls and bottom one-half inch in thickness, were immersed in water to a depth of about 2 inches after they had cured in moist air for one week. A mortar mixture of 1 part of cement to 3 parts of sand was used. Specimen No. 1, which contained no oil, showed a damp spot on the inside after immersion for about one minute. After one hour's immersion it was damp over the entire inner surface to a height somewhat greater than the level of the water in the dish. This was caused in part by capillarity. Within a few days water had penetrated this receptacle until the level inside was the same as that outside. The remaining three vessels, made of 1:3 mortar and mixed with 5, 10, and 20 per cent of oil, respectively, remained perfectly dry on the inside during immersion for one year.

All of these experiments have given very encouraging results and point to the use of oil-mixed mortars and concretes as a cheap and effective solution of the problem of waterproofing for a great many types of concrete construction.

MATERIALS USED.

As ordinarily made, concrete consists of a mixture of cement, sand, broken stone or gravel, and water. Oil-mixed concrete differs from ordinary concrete only in that oil is an additional ingredient in the mixture. It is important that the materials used in any concrete mixture be of the proper kind and be combined in the correct proportions for the work in hand.

CEMENT.

By far the best cement for use in oil-mixed concrete is Portland cement, not only because of its more uniform quality, but also because of its greater strength, which permits it to be mixed with a larger percentage of properly proportioned aggregate. For unimportant work it is usually safe to select a brand of cement of well-known reputation and use it without testing, although even for work of an insignificant character it is preferable to test the cement for its soundness or its liability to disintegrate.

A very quick test for soundness may be made by kneading some of the cement with enough water to form a paste of such consistency that it may be molded into a ball without crumbling. This ball, which should be about 1¼ inches in diameter, should be allowed to harden under a moistened cloth for 24 hours, after which it should be placed in a pan of cold water, and the water heated to the boiling point. If the cement ball shows no signs of cracking after boiling

for three hours and remains hard and not disintegrated in any way, the indications are strongly in favor of the fitness of the sample.

On work of any importance, the cement should be carefully sampled and tested by a testing laboratory equipped for that purpose.

SAND.

The character of the sand used in a concrete mixture has a marked effect on the strength of the concrete. The sand should be clean and coarse. It is not advisable to permit more than 5 per cent of silt or clay in the sand, since both of these materials tend to weaken a rich concrete mixture when present in large quantities. The sand grains should be coarse; that is, should be graded in size from one thirty-second up to one-eighth or one-fourth inch in diameter. Sand graded in size from small to large makes a denser and stronger mortar than sand of uniform size. Should fine sand be the only material available, it will be necessary to use an increased quantity of cement in order to obtain the same strength that would be obtained from the use of a coarser sand.

STONE.

The best rocks for concrete are, in general, the traps and granites, although some varieties of sandstone and limestone give very good results. Gravel which is clean makes an excellent material for use in concrete. The best results are usually obtained with stone graded in size from one-fourth inch up to $1\frac{1}{2}$ inches, but for reinforced work a maximum size of 1 inch is preferable. Whenever gravel is used, it should be screened through a one-fourth inch mesh screen and the finer particles should be later recombined with the coarser particles in the correct proportions. It is not a wise procedure to mix cement with the gravel as it comes from the bank, since the sand and larger pebbles are generally not proportioned correctly to obtain the densest and strongest concrete.

WATER.

The mixing water should be clean and free from all strong acids, alkalies, and vegetable matter.

SPECIFICATIONS FOR OIL TO BE USED IN OIL-CEMENT CONCRETE.

(Subject to revision.)

(1) The oil shall be a fluid petroleum product and shall contain no admixture of fatty or vegetable oils.

(2) It shall have a specific gravity not greater than 0.945 at a temperature of 25° C.

(3) It shall show a flash point of not less than 150° C. by the closed-cup method.

(4) When 240 cc. of the oil is heated in an Engler viscosimeter to 50° C., and maintained at that temperature for at least three minutes, the first 100 cc. which flows out shall show a specific viscosity of not less than 15 nor more than 30.

(5) When 1 part of the oil is shaken up with 2 parts of hundredth normal caustic soda, there shall be no emulsification, and upon allowing the mixture to remain quiet the two components shall rapidly separate in distinct layers.

The general purpose of the above clauses is as follows:

Clause 1 eliminates compounded products in which the presence of saponifiable oils would break down the strength of the cement. Clause 5 has a similar purpose in eliminating certain straight petroleum residuals which readily emulsify with alkali, and seriously impair the strength of the mortar to which they are added. Clauses 2, 3, and 4 combine to prevent the use of certain asphaltic oils which prove detrimental to the strength of the concrete, and clause 4, in particular, prescribes an oil of such viscosity as to be readily miscible with the mortar, while still possessing sufficient body to render the structure damp proof.

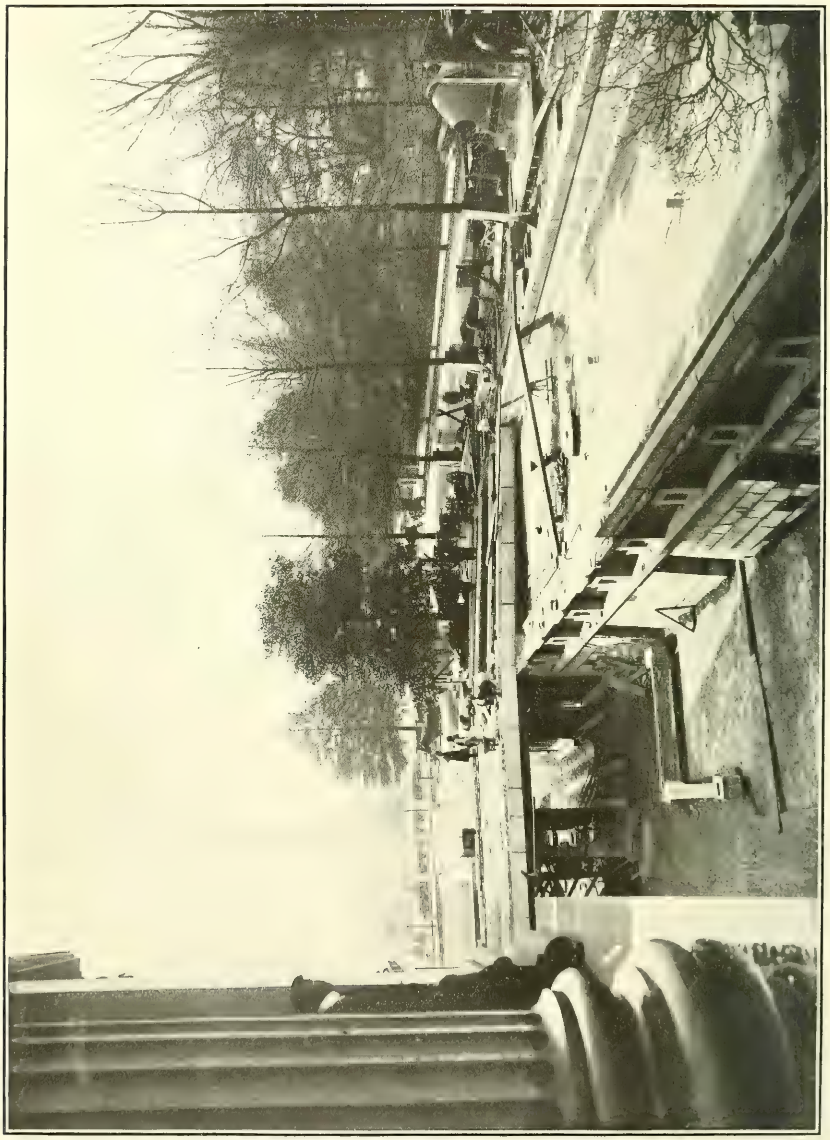
METHOD OF MAKING.

For most purposes where damp-proofing is required 5 per cent of oil based on the weight of cement in the mixture is all that is necessary. A bag of cement weighs 94 pounds, and consequently, for each bag of cement used in the mixture, 4.7 pounds or about 2½ quarts of oil are required.

Let it be supposed that a batch of concrete requiring two bags of cement is to be mixed in the proportions of 1 part of cement to 2 parts of sand to 4 parts of broken stone or gravel, together with 5 per cent of oil. Four cubic feet of sand are first measured out in a bottomless box 12 inches deep and 2 feet on each side. On top of the sand is spread the cement and these materials are mixed together until they appear to be of uniform color. Water is then added to the mixture and the mass again mixed to a mortar of mushy consistency. Five quarts of oil are then measured out and added to the mortar, and the mass again turned until there is no trace of oil visible on the surface of the mortar. Particular care should be taken to continue the mixing until the oil is thoroughly incorporated in the mixture. Experience has shown that to insure the very best results the length of time of mixing should be practically double that required when oil is not used. The oil-mixed mortar is then combined with the stone or gravel previously moistened and the mass is again turned until all of the stone is thoroughly coated with the mortar and the mass is uniformly mixed throughout. Should only oil-mixed mortar be desired, the process is similar to that above described except that no stone is added.

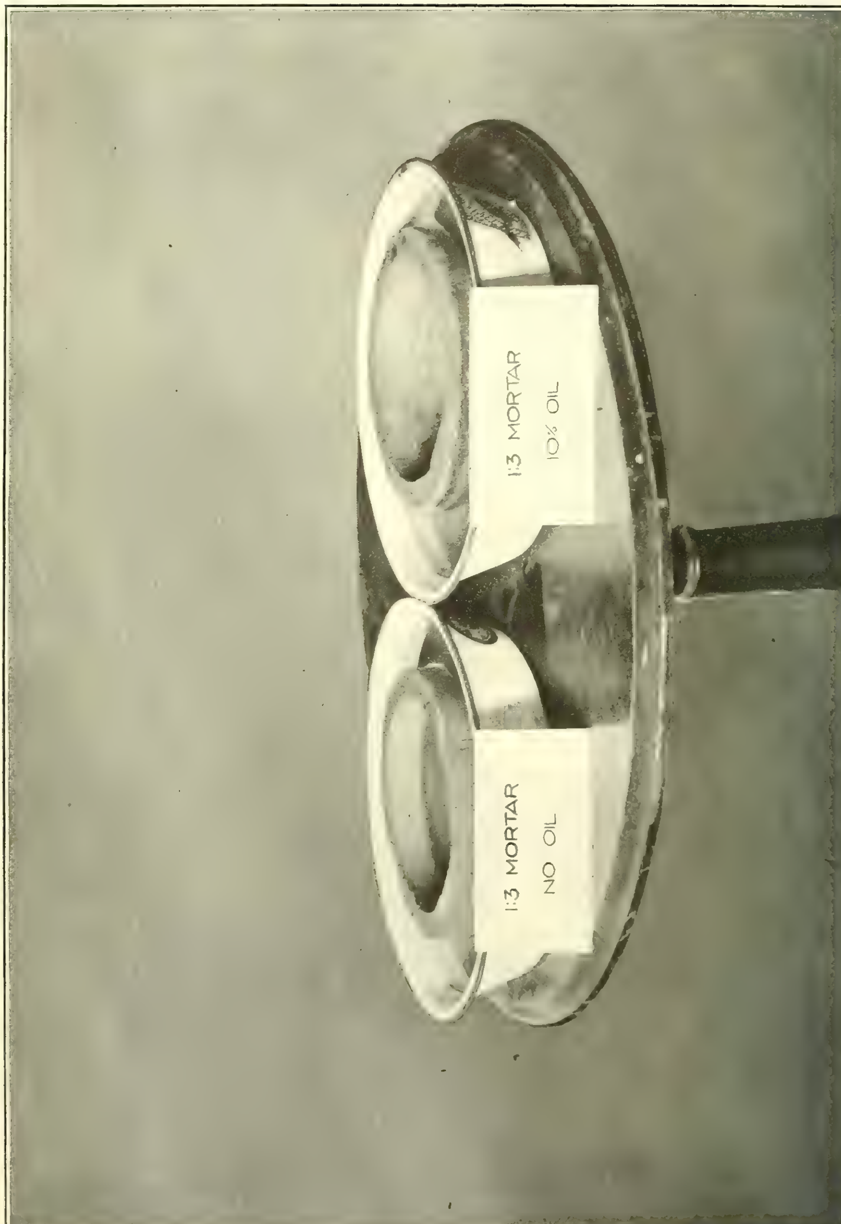
BRIQUETTES SHOWING REPELLENT ACTION OF OIL-CEMENT CONCRETE ON ALKALI WATER.

Top row contained 10 per cent of semiasphaltic oil; middle row contained 5 per cent of semiasphaltic oil; bottom row contained no oil. Briquettes were immersed one year in a 10 per cent solution of sodium sulphate.



VAULTS IN THE UNITED STATES TREASURY BUILDING.

CONSTRUCTING ROOF OF VAULTS IN THE UNITED STATES TREASURY BUILDING (DETAILED VIEW).



LABORATORY TEST OF OIL-MIXED MORTAR.

In a machine mixer the cement, sand, and water are first mixed to a mortar, when alternate batches of oil and stone are added until the required quantity of oil is mixed, and then the remainder of the stone is added and mixed. When a batch mixer is used, the exact method of procedure should be determined by experiment, owing to the fact that different makes of mixers require slightly different handling to insure best results. A continuous mixer should not be used in oil-cement-concrete work, as with this type the time of mixing can not readily be increased to the extent necessary to insure a uniform distribution of the oil.

MATERIALS REQUIRED FOR 1 CUBIC YARD.

The following table gives the proportions by parts and amounts required of cement, sand, stone, and oil to make a cubic yard of oil-mixed mortar and concrete:

TABLE 2.—*Quantities of materials required for 1 cubic yard of oil-mixed mortar and concrete.*

Proportions by parts.				Cement (barrels[1]).	Sand (cubic yards).	Stone or gravel (cubic yards).	Oil (gallons[2]).
Cement.	Sand.	Stone or gravel.	Oil (percent).				
1	...	...	3	8.31	...	...	12.1
1	2	...	5	3.32	0.93	...	8.06
1	3	...	5 10	2.48	1.05	...	6.02 12.04
1	4	...	5 10	1.98	1.11	...	4.8 9.61
1	2	4	5	1.57	.44	0.88	3.81
1	$2\frac{1}{2}$	5	5 10	1.30	.46	.92	3.15 6.3
1	3	6	5 10	1.11	.47	.94	2.69 5.38

[1] One barrel of cement equals 4 bags.

[2] Oil weighs about $7\frac{3}{4}$ pounds per gallon.

USES.

All of the laboratory and service tests thus far made on oil-mixed mortars and concretes are indicative of a wide future usefulness for these materials, principally in damp-proof construction. There are many types of structures through which the permeation of moisture is ruinous to either the appearance or the efficiency of the construction, or is seriously detrimental to the health of either animal or human life. The efflorescence due to the leaching out and subsequent carbonization of the lime on the surface of a concrete wall might well be prevented by the incorporation of an agent capable of excluding all moisture. Again, the dampness of many cellars, with its danger to health, could have been prevented had the walls and floors been damp-proofed. The following types of structures might be damp-proofed at an exceedingly slight extra expense by the incorporation of a small amount of the proper kind of mineral oil residuum

with the mortar or concrete used in construction: Basement floors, basement walls, watering troughs, cisterns, barns, silos, irrigating canals, the concrete base for bituminous concrete and asphalt roadways, concrete blocks, roofs, stucco, and numerous important engineering constructions.

BASEMENT FLOORS.

A basement floor which will remain perfectly dry may be constructed at a cost but very slightly higher than that of the ordinary basement floor by the incorporation of a petroleum residuum oil with the ordinary concrete mixture. The following method of construction, using an oil-cement mixture, is suggested as one which will prevent the permeation of moisture even from a very wet subsoil.

It will be well, if the underlying soil is very wet, to lay a 6-inch foundation of sand, cinders, broken stone, or gravel, compacting these materials well by tamping. In addition, it will be of advantage to employ drain tiles in this porous foundation, leading them to a sewer if possible. On top of the foundations should be laid a 4-inch layer of concrete mixed in the proportions of 1 part of Portland cement, 2½ parts of sand, and 5 parts of broken stone or gravel. Before the concrete base has hardened, a top or wearing coat of mortar mixed in the proportions of 1 part of cement and 2 parts of sand or stone screenings, and containing 5 per cent of oil (2½ quarts per bag of cement) should be laid. This top coat, because of its nonabsorbent character, will give perfect protection from underlying moisture, and moreover it will build a floor which will dry out very quickly after washing, since practically none of the washing water will be absorbed.

It might be thought that the addition of oil to the mortar wearing coat would tend to make the surface slippery. Such, however, is not the case; nor is the appearance very much different from that of an ordinary cement floor. Should joints be provided for expansion and contraction, it will be necessary to fill them with a good bituminous filler to prevent the entrance of water.

Many cellar floors now made of Portland cement concrete are giving trouble owing to the permeating moisture. They are continually damp and, owing in part to the constant evaporation from their surface, they are cold. Such a condition may be remedied by the application of an oil-mixed mortar coat to the surface of the old floor. Before attempting to lay the new wearing surface, the old floor should be scrubbed thoroughly clean and should be made thoroughly wet. The bond between the old and the new work will be improved if the old surface be roughened with a stone hammer. A wash composed of 1 part of hydrochloric acid and 5 parts of water may be used to clean the surface. This will dissolve some of the cement from the old work, leaving the aggregate exposed. The acid

solution should be left on not longer than half an hour, when it should be completely removed with clean water. The surface should then be brushed with a wire or stiff scrubbing brush to remove any particles of sand which may have become loosened because of the dissolving of the cement.

A mortar composed of 1 part of cement and 2 parts of sand and containing 5 per cent of oil will be sufficiently nonabsorbent for the new wearing coat. To strengthen the bond it will be well to apply a wash of grout, made by mixing cement with water to the consistency of cream, before laying the oil-mixed mortar coat. For the ordinary basement floor a 1-inch layer of mortar will prove of sufficient thickness. It will be necessary to keep the new mortar damp for at least one week in order that it may attain its proper strength.

CELLAR WALLS.

The entrance of moisture through the walls is another common source of damp basements. The water pressure in the soil adjacent to the wall is very seldom of great magnitude, so that a material nonporous and at the same time impermeable under moderate pressures is the logical one to use for this type of construction.

A concrete mixture in the proportions of 1 part of cement, 2½ parts of sand, and 5 parts of gravel or broken stone, together with 10 per cent of oil based on the weight of cement in the mixture, should prove amply rich for most situations. A wall of these proportions, 12 inches thick and provided with a spread footing, will withstand a pressure of 6 feet of earth. When supported at the top by floor joists, a much thinner wall may be used with safety. A 6-inch wall 7 feet high may be used to withstand 6 feet of earth pressure. Generally speaking, such a thin wall should be reinforced by deformed steel rods spaced about 2 feet apart in both directions. Any of the many types of deformed bars, made especially for reinforcing, may be used with perfect results. Care should be taken that the earth is not filled in against the back of the wall for at least four weeks after pouring the concrete, unless the wall is braced on the inside by allowing the inner forms to remain in place.

Many basement walls now built of stone, brick, or concrete are giving trouble through leakage. The application of a plaster coat of oil-mixed mortar composed of 1 part of cement, 2 parts of sand, 5 per cent of oil, and enough water to form a rather stiff mortar, will prove an efficient remedy for this trouble. The surface to which this mortar is to be applied should be roughened with a stone hammer, if the old wall is of concrete, or the mortar joints should be raked out to a depth of half an inch from brick or masonry walls. The acid wash previously described should be applied to cleanse the surface thoroughly, after which the loose particles must be removed with a wire

brush or a stiff bristles brush. It will be impossible to obtain a water-tight coating if it is applied while water is seeping through the wall. It will be well to wait for the dry season, when the ground water is reduced to its lowest level, before attempting to waterproof by plastering. Should water appear to be coming through a well-defined crack in the wall, calking with oakum or cotton may be resorted to in order to stop the leakage until a plaster coat of oil-mixed mortar can be applied. It will be necessary to mix the mortar for plastering to a rather dry consistency, and it should be troweled hard in order to obtain a hard, dense waterproof surface. A wash of cement and water mixed to the consistency of thick cream and applied before the oil-mixed mortar coat is put on will aid the new mortar in adhering to the old work. The old wall must be thoroughly wet before the new mortar coat is applied.

WATERING TROUGHS.

The use of oil-mixed concrete in the construction of watering troughs will be found to give excellent results in maintaining them in an absolutely water-tight condition.

For this purpose a mixture of 1 part of Portland cement, 2 parts of clean coarse sand, and 4 parts of gravel ranging in size from $\frac{1}{4}$ inch to 1 inch is recommended. The mixture should likewise contain 10 per cent of oil based on the weight of cement and should be mixed to a jellylike consistency. It will be well to provide wire-mesh or steel-rod reinforcement for the bottom and walls. Care should be taken to puddle the concrete into place thoroughly and to trowel or spade the material next to the molds. This flushes the mortar to the surface, making it smooth and dense, and rendering a finishing coat of plaster unnecessary. Should a very smooth surface be desired, an effective finish may be obtained by applying several paint coats of oil-mixed cement grout made as follows: Enough water should be mixed with cement to form a paste of soft, putty-like consistency. To this paste should be added 3 per cent of oil, based on the weight of dry cement in the mixture (a 10-quart bucket of dry cement requires about a pint of oil for this purpose), and the whole should be mixed until the oil is entirely combined with the other ingredients. The paste may now be thinned down with more water to the consistency of cream, after which it may be applied with a stiff brush to the previously dampened concrete. A second coat of this oil grout should be applied after the first coat has hardened. Care should be taken that it does not dry out too quickly by applying it to the dry concrete or exposing it to the direct rays of the sun. A trough or tank built as described will be absolutely water-tight, and, furthermore, the waterproofing will have cost almost nothing in comparison with the costs of the other materials.

CISTERNS.

For waterproofing cisterns, oil-mixed concrete will prove of great benefit. It is absolutely necessary that cisterns which are buried in the ground be waterproofed to prevent contaminated ground water from seeping in, as well as to prevent the cistern water from escaping. Buried cisterns of rectangular shape should be reinforced to resist the earth pressure, which tends to bulge the side walls inward when the water runs low. The reinforcement should, therefore, be provided on the inside or tension side of the walls. The earth pressure will prevent the tank from cracking when it is full of water.

For cistern construction a mixture composed of 1 part of cement, 2 parts of sand, and 4 parts of gravel or broken stone, together with 10 per cent of oil, is effective. The inner faces of the cistern should be painted with an oil-mixed cement grout applied with a stiff brush and rubbed well into the face of the wall. Two coats of this grout, containing about 3 per cent of oil, should be used.

BARNS.

Barns constructed of concrete are gradually coming into use because of their durability, cleanliness, resistance to fire, and economy. It is essential that the interior of these structures be kept free from moisture, and for this reason it is well to waterproof the concrete mixture entering the side walls and flooring. The side walls, unless waterproofed, have a tendency during a long beating rain to absorb and retain much moisture, and this moisture penetrates to the interior.

If oil in amount equal to 5 per cent of the weight of cement be mixed with the concrete used in the side walls, this damp condition of the interior becomes impossible, because the admixture of oil prevents the penetration of the moisture.

Barn floors should be waterproofed by the addition of oil as previously described. A damp-proof floor has the advantage of remaining dry and hence warmer, because there is no evaporation from the surface. It is likewise more sanitary than an ordinary concrete floor because of its nonabsorbent character.

CONCRETE BLOCKS.

The use of concrete blocks in the building trade is yearly increasing. Much criticism has been heaped on the building block, and in many cases the criticism has been just. It is recognized that many concrete-block houses are damp, owing to the fact that the walls are very porous and absorb and retain much moisture after a heavy, beating rain. A building block generally need not be waterproofed against water pressure, but it should, however, be rendered proof against the permeation of water by absorption. The use of a small quantity of mineral oil in a concrete block renders it extremely non-

absorbent, so that even after a hard rain there is no danger from damp walls. In a 1:2:4 mixture, 5 per cent of oil is a sufficient quantity to waterproof properly against absorption.

ROOFS.

Portland cement mortar mixed with mineral oil and reinforced with steel-wire mesh may be advantageously used in the construction of roof slabs. These slabs could be assembled in place on the roof after they have attained sufficient hardness. Reinforced concrete tiles may also be advantageously made with Portland cement concrete mixed with a small percentage of mineral-oil residuum.

STUCCO.

Portland cement stucco is widely used in the construction of many residences. This type of construction is economical, and, moreover, with it many beautiful effects are possible. The term "stucco" is given to the exterior finish coat, which may be applied to brick, stone, concrete, hollow tile, or frame construction. According to the finish desired and the kind of surface to be covered, the stucco is applied in two or three coats. The first, or scratch coat, should be mixed in the proportions of 1 part of Portland cement and 2 parts of clean, coarse sand, with enough water to form a good stiff mortar. If 5 per cent of oil is added to this mixture, the scratch coat will be permanently waterproof. While this coat is still wet, it is roughened with a stick or trowel over the entire surface. The second coat, which may be of the same proportions, is plastered on after the first coat has set sufficiently to support it. The use of oil in this coat may be omitted if desired, and it may be given a rough-cast finish by using a trowel covered with burlap or carpet.

The second coat may also be applied by throwing it on with a wooden paddle. This produces a rough surface known as a slap-dash finish. A pebble-dash surface may be secured by using a wet mixture composed of 1 part cement and 3 parts pebbles one-fourth inch in diameter. This mixture is thrown on the second coat while it is still soft, and the result is a very pleasing surface. When a pebble-dash finish is used, the second coat, as well as the scratch coat, may be mixed with oil. In most constructions the second coat will be found superfluous, because a sufficiently thick coating is usually obtained from the first application of oil-mixed mortar.

When stucco is applied to stone or hollow tile, care should always be taken to have the surface well moistened or otherwise a great deal of water will be absorbed from the mortar coat, and so greatly weaken it and cause contraction cracks to form.

IRRIGATION DITCHES.

The results of laboratory tests, previously referred to, which indicate that the presence of oil tends to retard very materially the

action of alkalies on concrete, suggests that another field for the use of oil-cement concrete may be found in the construction of linings for irrigating canals and ditches. Many of these canals are in localities where the soil is strongly impregnated with alkali salts and where the water carried contains alkali in solution. The destructive action of alkali is undoubtedly due to the crystallization of the salts within the mass of the concrete, or the formation by chemical action of compounds of greater volume than the original salts, or to a combination of both of these actions.

As the admixture of oil will retard the absorption of water into the concrete, it should materially lengthen the life of the lining. In the mixing of concrete for this purpose it is, of course, necessary to avoid the use of either water or sand containing alkali.[1]

CONCRETE BASE FOR ROADWAYS.

The use of this material should also prove of value for damp-proofing the concrete base of roads against the action of ground water, which if allowed to pass through will tend to disintegrate the road surface. Such action as this is particularly noticeable with road surfaces such as asphalt, bituminous concrete, etc. Assuming the usual proportions for the concrete base, etc., 10 per cent of oil should prove sufficient for this purpose.

ENGINEERING CONSTRUCTIONS.

There are many important engineering constructions in which oil-mixed mortar or concrete may be advantageously employed. Among them may be mentioned aqueducts, buildings, burial vaults, boats, foundations, gutters, mausoleums, roofs, sewers, troughs, tanks, and wells. In some constructions a coat of oil-mixed mortar is effective, while in others oil-mixed concrete may be used throughout.

It is confidently believed that, if carefully prepared oil-mixed concrete is used in structures of any kind requiring damp-proofing—and in such structures careful work is a very important factor in the result—there will be no difficulty experienced from leakage and the structures will have been damp-proofed at very little extra expense.

[1] More detailed information relative to the use of oil-cement concrete for this purpose may be secured by reference to Bulletin No. 126 of the Department of Agriculture.

APPENDIX.

PHYSICAL TESTS OF OIL-MIXED PORTLAND-CEMENT CONCRETE.

In order to investigate the physical properties of oil-mixed Portland-cement concrete, the following physical tests were conducted in the testing laboratory of the Office of Public Roads: (1) Tensile strength, (2) crushing strength, (3) time of setting, (4) toughness or resistance to impact, (5) stiffness or modulus of elasticity, (6) absorption, (7) permeability, and (8) bond tests.

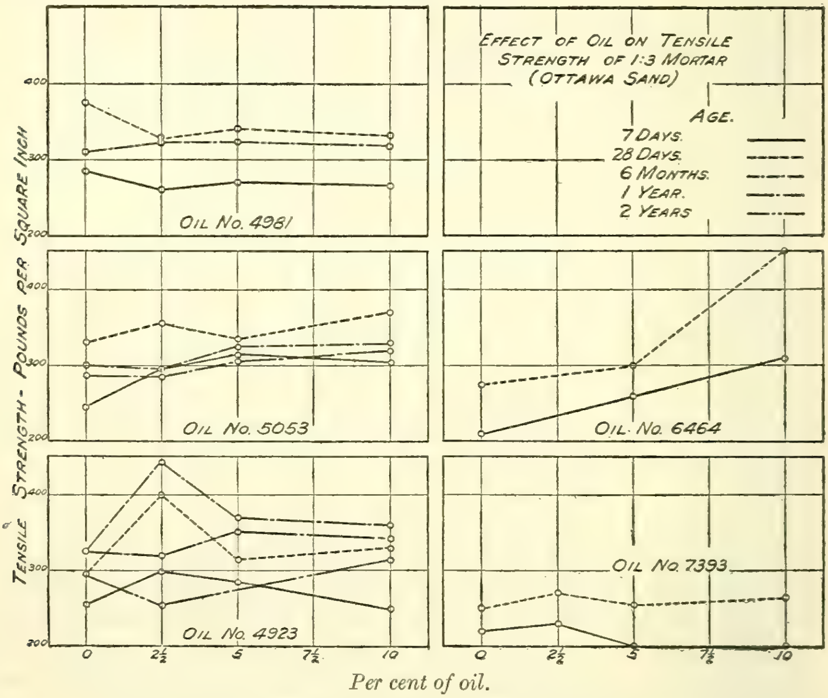


FIG. 1.—Effect of oil on tensile strength of 1:3 mortar.

The materials used consisted of Portland cement, river sand, crusher-run gneiss, river gravel, and various kinds of petroleum residuum oils.

The mechanical analysis of the sand, stone, and gravel used is given below:

TABLE 3.—*Mechanical analysis of sand, stone, and gravel.*

Sand.		Stone.		Gravel.	
Sieve No.	Per cent retained.	Sieve No.	Per cent retained.	Sieve No.	Per cent retained.
		Inch.		*Inch.*	
¼ inch	3	¾	28.4	1	4.2
⅛ inch	11	½	66.3	¾	8.4
10	17	¼	92.1	½	30.2
20	42	⅛	98.4	¼	80.2
30	66			⅛	97.7
40	87				
50	93				
80	96				
100	99				

There were 37 per cent of voids in the sand, 43 per cent in the stone, and 37 per cent in the gravel.

The cement passed the specifications of the American Society for Testing Materials.

Various types of oils were used, and these are described in the following table:

TABLE 4.—*Analysis of oils used in oil-cement-concrete mixtures.*

	Sample No.—									
	4145	4146	4147	4149	4170	4923	4981	5053	6464	7393
Type	[1]	[1]	[1]	[1]	[2]	[1]	[1]	[1]	[1]	[1]
Character	[3]	[3]	[3]	[3]	[4]	[3]	[5]	[5]	[3]	[3]
Specific gravity at 25°/25° C	0.924	0.910	0.926	0.923	....	0.945	0.893	0.924	0.904	0.949
Per cent of loss at 163° C., 5 hours (20 grams)	6.86	12.56	7.98	7.02	18.38	1.35	27.17	3.70	0.10	19.38
Character of residue	[3]	[3]	[3]	[3]	[6]	[3]	[7]	[8]	[9]	[4]
Per cent of bitumen soluble in CS_2 air temperature	99.99	99.99	99.93	99.95	99.81	99.96	99.95	99.90	99.90	99.95
Per cent of organic matter insoluble	.01	.01	.07	.05	.13	.04	.02	.07	.10	.05
Per cent of inorganic matter insoluble	.00	.00	.00	.00	.06	.00	.03	.03	.00	.00
Total (per cent)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	2.23	6.82	10.16	2.24	16.87	3.46	1.00	4.12	1.10	2.45
Fixed carbon	2.41	3.36	5.11	1.98	....	4.18	1.77	2.82	1.17	2.87
Specific viscosity, Engler, 50° C.	14.20	6.40	18.20	20.20	....	65.10	2.50	17.40	13.50	12.20

[1] Fluid residual oil.
[2] Cut-back oil asphalt.
[3] Fluid, greasy.
[4] Fluid, sticky.
[5] Fluid, slightly sticky.
[6] Semisolid, sticky.
[7] Slightly granular, more viscous than original.
[8] Fluid, granular in appearance.
[9] Very viscous, greasy fluid, rather lumpy; surface waxy.

TENSILE STRENGTH.

TABLE 5.—*Tensile strength (1:3 mortar, Ottawa sand).*

Age in days.	Per cent of oil.	Laboratory No. of oil.				
		4923	4981	5053	6464	7393
7	0	256	283	244	210	221
	2½	299	259	297	....	230
	5	287	268	313	258	200
	10	252	264	304	308	195
28	0	296	376	331	275	250
	2½	400	327	353	....	270
	5	316	341	334	298	253
	10	331	329	371	403	260
180	0	326	312	302	....	....
	2½	449	323	298	....	....
	5	372	321	325	....	....
	10	360	319	330	....	....
360	0	326	....	288	....	....
	2½	320	....	286	....	....
	5	353	....	309	....	....
	10	343	....	320	....	....
720	0	293	....	....	....	....
	2½	257	....	....	....	....
	5	....	....	....	....	....
	10	315	....	....	....	....

The foregoing results are plotted on figure 1. It will be noticed that, in general, the specimens containing oil have a higher tensile strength than those without oil.

CRUSHING STRENGTH.

Specimens of mortar and concrete containing different percentages of various kinds of oils were molded 6 inches in diameter and 6 inches high. They were bedded in plaster of Paris and blotting paper, and crushed at a speed of 0.152 inch per minute. Table 6 gives the crushing strength of 1:3 oil-mortar specimens for periods of 28, 180, and 360 days; and Table 7, the crushing strength of oil-concrete cylinders tested at various periods up to two years. The results are plotted on figures 2 and 3. It will be noted that the crushing strength is decreased by the addition of oil, but that the decrease is not serious when the amount of oil does not exceed 10 per cent. It will also be noted that oil-mixed cement concrete gains in strength with time in about the same ratio as untreated concrete. This fact indicates that the addition of oil to the mixture in small amounts has no disintegrating effect on the cement. This statement holds true for periods up to and including two years.

TABLE 6.—*Compression test of oil-mortar 6 by 6 inch cylinders, proportions 1:3 by weight.*

Specimen No.	Per cent of oil.	Oil No.	Air cured.			Water cured.		
			28 days.	180 days.	360 days.	28 days.	180 days.	360 days.
1	0	....	1,170 (5)	1,350 (2)	1,597 (2)	2,135 (6)	2,275 (2)	2,308 (2)
17	5	4145	1,050 (2)	830 (2)	1,220 (2)	1,715 (2)	2,160 (2)	2,240 (2)
2	10	4145	790 (1)	....	....	1,320 (1)	....	....
22	15	4145	895 (2)	780 (2)	880 (2)	1,290 (2)	1,615 (2)	1,700 (2)
27	20	4145	775 (2)	910 (2)	1,125 (2)	1,020 (2)	1,420 (2)	1,425 (2)
18	5	4146	915 (2)	....	1,110 (2)	1,770 (2)	....	2,560 (2)
3	10	4146	830 (1)	....	....	2,400 (2)	....	....
23	15	4146	1,215 (2)	1,275 (2)	1,670 (2)	1,775 (2)	2,410 (2)	2,475 (2)
28	20	4146	935 (2)	1,295 (2)	1,380 (2)	1,345 (2)	1,640 (2)	1,780 (2)
19	5	4147	1,405 (2)	1,155 (2)	1,715 (2)	1,995 (2)	2,475 (2)	2,700 (2)
4	10	4147	1,070 (1)	....	....	1,720 (1)	....	....
24	15	4147	975 (2)	1,085 (2)	1,435 (1)	1,670 (2)	2,350 (2)	2,250 (1)
29	20	4147	795 (2)	1,055 (2)	1,310 (2)	1,400 (2)	2,010 (2)	1,895 (2)
21	5	4149	1,305 (2)	1,105 (2)	1,395 (2)	2,220 (2)	2,655 (2)	2,450 (1)
6	10	4149	1,170 (1)	....	....	1,750 (1)	....	....
26	15	4149	1,440 (2)	1,395 (2)	1,330 (2)	1,895 (2)	2,215 (2)	2,320 (2)
31	20	4149	925 (2)	1,085 (2)	1,135 (2)	1,230 (2)	1,475 (2)	1,530 (2)
7	5	4170	1,010 (2)	940 (2)	1,315 (2)	1,760 (2)	2,065 (2)	2,345 (1)
8	10	4170	980 (2)	1,005 (2)	1,510 (2)	1,680 (2)	1,825 (2)	2,200 (1)
9	15	4170	1,055 (2)	1,170 (2)	1,555 (2)	1,265 (2)	1,365 (2)	1,685 (1)
10	20	4170	890 (2)	1,220 (2)	1,325 (2)	1,175 (2)	1,340 (2)	1,375 (1)

NOTE.—Numbers in parentheses indicate number of specimens tested.

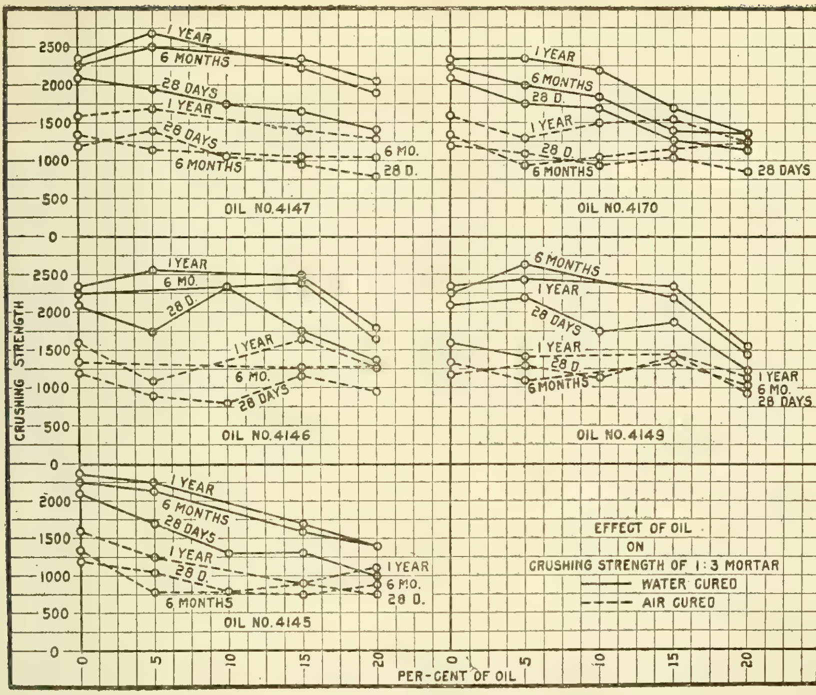


FIG. 2. Effect of oil on crushing strength of 1:3 mortar.

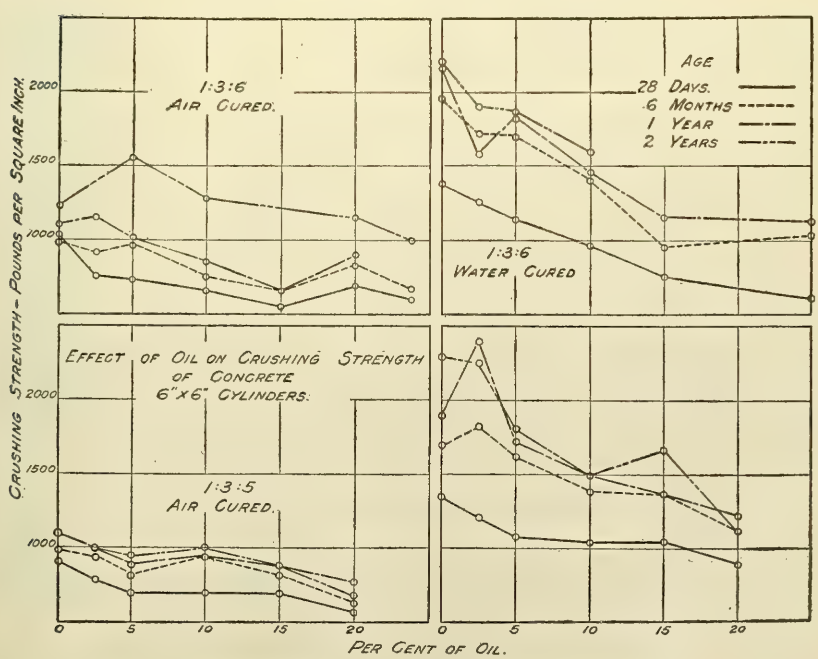


FIG. 3.—Effect of oil on crushing strength of concrete.

TABLE 7.—*Compression tests of oil-concrete 6 by 6 inch cylinders.*

Specimen No.	Oil No.	Proportions.	Per cent oil.	Air cured.				Water cured.			
				28 days.	180 days.	360 days.	720 days.	28 days.	180 days.	360 days.	720 days.
6	.....	1:3:6	0	1,020 (3)	980 (2)	1,090 (3)	1,225 (2)	1,370 (2)	1,955 (3)	2,170 (3)	2,205 (2)
7	4923	1:3:6	2½	750 (2)	915 (2)	1,165 (2)	....	1,253 (3)	1,715 (2)	1,580 (3)	1,900 (2)
8	4923	1:3:6	5	737 (2)	975 (2)	1,015 (2)	1,560 (2)	1,142 (2)	1,690 (2)	1,835 (2)	1,865 (2)
9	4923	1:3:6	10	656 (2)	755 (2)	850 (1)	1,230 (1)	961 (3)	1,400 (2)	1,440 (3)	1,585 (2)
10	4923	1:3:6	15	542 (2)	670 (2)	675 (2)	....	750 (2)	995 (2)	1,145 (3)	....
11	4923	1:3:6	20	695 (2)	840 (2)	900 (2)	1,150 (1)	1,120 (2)	1,535 (2)	1,670 (3)	1,975 (2)
12	4923	1:3:6	25	605 (3)	678 (2)	....	1,005 (2)	620 (2)	1,030 (2)	1,120 (3)	....
13	.....	1:3:5	0	920 (2)	998 (1)	1,010 (2)	1,100 (2)	1,342 (2)	1,705 (2)	1,890 (2)	2,300 (2)
14	4923	1:3:5	2½	787 (2)	945 (3)	995 (3)	1,010 (2)	1,222 (2)	1,830 (3)	2,410 (3)	2,250 (2)
15	4923	1:3:5	5	715 (2)	822 (2)	912 (3)	940 (2)	1,082 (2)	1,626 (2)	1,715 (3)	1,805 (2)
16	4923	1:3:5	10	698 (2)	965 (2)	975 (3)	1,010 (3)	1,040 (2)	1,406 (2)	1,490 (3)	1,480 (3)
17	4923	1:3:5	15	693 (2)	828 (3)	888 (3)	888 (2)	1,040 (2)	1,380 (2)	1,382 (3)	1,680 (3)
18	4923	1:3:5	20	572 (2)	639 (2)	772 (2)	672 (2)	904 (2)	1,115 (2)	1,230 (3)	1,130 (2)
164	.....	1:1.5:4.5	0	1,880 (2)	2,050 (2)	2,365 (2)	....	2,185 (2)	2,670 (2)	2,950 (2)	2,850 (2)
168	4981	1:1.5:4.5	2½	1,345 (2)	1,490 (2)	1,560 (1)	1,855 (2)	1,795 (2)	2,330 (2)	2,250 (2)	2,700 (2)
169	4981	1:1.5:4.5	5	1,250 (2)	1,145 (2)	1,768 (2)	1,585 (2)	1,925 (2)	2,355 (2)	2,750 (2)	2,800 (2)
177	4981	1:1.5:4.5	10	980 (2)	845 (2)	1,170 (3)	1,035 (2)	1,065 (2)	1,485 (2)	1,625 (2)	1,568 (2)
479	.....	1:2:4	0	....	....	....	....	1,920 (2)	3,280 (2)	3,350 (2)	3,370 (2)
480	4923	1:2:4	2½	....	....	....	....	2,420 (2)	3,430 (2)	3,390 (2)	3,130 (2)
481	4923	1:2:4	5	....	....	....	....	2,750 (2)	3,270 (2)	3,110 (2)	3,160 (2)
482	4923	1:2:4	10	....	....	....	....	2,160 (3)	2,820 (2)	3,020 (3)	....
800	.....	1:1.5:4.5	0	1,680	....	....	....	2,020	....	....	....
801	7393	1:1.5:4.5	2½	1,370	....	....	....	1,955	....	....	....
802	7393	1:1.5:4.5	5	1,290	....	....	....	1,815	....	....	....
803	7393	1:1.5:4.5	10	1,175	....	....	....	1,385	....	....	....
796	.....	1:1.5:4.5	0	990	....	....	....	1,948	....	....	....
797	7393	1:1.5:4.5	2½	911	....	....	....	1,710	....	....	....
798	7393	1:1.5:4.5	5	738	....	....	....	1,290	....	....	....
799	7393	1:1.5:4.5	10	548	....	....	....	1,057	....	....	....

NOTE.—Figures in parentheses indicate number of specimens tested. Gravel used as coarse aggregate in Nos. 479, 480, 481, 482, 796, 797, 798, 799. Crushed gneiss used in all other tests.

TIME OF SETTING OF PORTLAND CEMENT.

TABLE 8.—*Effect of oil on time of setting.*

Oil No. 4923.		
Per cent of oil.	Initial set.	Final set.
	H. m.	*H. m.*
0	1 18	3 43
2½	1 31	4 56
5	1 57	5 27
10	2 27	5 57

The time of setting is delayed with the addition of oil, as shown by the above tests, which are plotted on figure 4. These results were obtained with the Gillmore needles on specimens subjected to identical conditions while hardening. Five per cent of oil delays the initial set by 50 per cent and the final set by 47 per cent.

TOUGHNESS OR RESISTANCE TO IMPACT.

The toughness or resistance to impact was tested on the Page impact machine under the blows of a 10-kilogram hammer falling on a 5-kilogram plunger from successively increasing heights of 1 centimeter. The height of the blow causing failure corresponds to the number of blows. The end of the plunger in contact with the

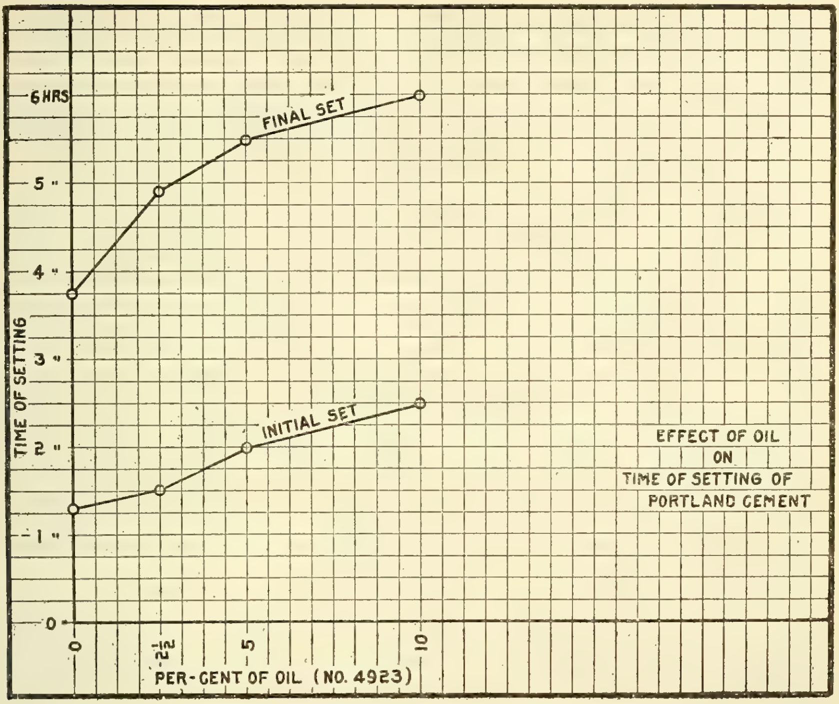


FIG. 4.—Effect of oil on time of setting of Portland cement.

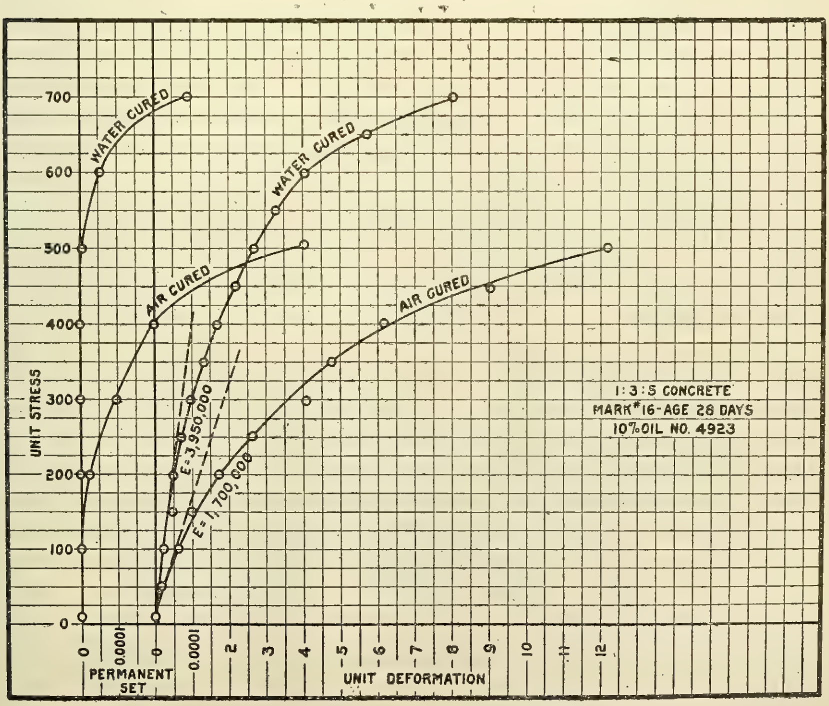


FIG. 5.—Modulus of elasticity and permanent set.

specimen is spherical in shape, with a radius of 3 centimeters. Specimens 6 inches in diameter and 6 inches high were tested after first bedding them in plaster of Paris before mounting on the anvil of the machine. The following results show that the toughness of concrete is very little influenced by the addition of a small amount of oil to the mixture:

TABLE 9.—*Number of blows required to produce failure.*

Per cent of oil No. 4923.	1:3:5 concrete.		1:3:6 concrete.	
	Air-cured.	Water-cured.	Air-cured.	Water-cured.
0	18	15	15	21
2½	15	33	14	18
5	23	20	15	20
10	13	20	12	21
15	14	20	13	16

A view of the impact machine with a specimen under test is shown in Plate V.

STIFFNESS OR MODULUS OF ELASTICITY.

For testing the effect of oil on the stiffness of concrete, specimens 8 inches in diameter and 16 inches high were made. The deformations under various loads were measured with a double micrometer-screw compressometer of the type described by J. M. Porter in the Proceedings of the American Society for Testing Materials, Volume X, 1910. Loads were applied in 2,500 and 5,000 pound increments and were released to 500 pounds after each increment of 5,000 pounds, and deformation readings were taken for permanent set. Typical stress deformation and permanent set curves are shown in figure 5. In all cases the initial modulus of elasticity was obtained from the slope of the stress-strain curve at its origin. A view of a specimen mounted in the testing machine with compressometer attached is shown in Plate VI.

TABLE 10.—*Initial modulus of elasticity (age 28 days).*

Per cent of oil No. 4923.	1:3:5 concrete.		1:3:6 concrete.	
	Air-cured.	Water-cured.	Air-cured.	Water-cured.
0	1,300,000	2,550,000	1,300,000	2,200,000
2½	1,350,000	2,700,000	1,000,000	2,400,000
5	1,250,000	2,350,000	850,000	1,900,000
10	1,700,000	3,950,000	1,150,000	1,900,000
15	1,300,000	2,500,000	730,000	2,050,000

The above results show that oil has little effect on the stiffness of concrete. The increased value of the modulus of elasticity of the

water-cured over the air-cured specimens is as marked in the oil-mixed as in the plain specimens. Tests at one year, although not here recorded, show that oil-mixed concrete gains as much in stiffness with age as the plain concrete does.

ABSORPTION.

The resistance of concrete to the penetration of moisture is measured by its absorptive qualities. To test the absorption of oil-mixed concrete compared with plain concrete, cylindrical specimens 6 inches in diameter and 6 inches high were dried to constant weight in an oven, after being cured for 15 days in air. They were then immersed in water and weighed from time to time. The results of these tests are plotted on figure 6. It will be seen that the oil greatly decreases the percentage of absorption; the cylinder containing 10 per cent of oil absorbed 1.7 per cent of water, based on the dry weight, while the cylinder containing no oil absorbed 6.25 per cent.

PERMEABILITY.

To investigate permeability, specimens 3 inches in thickness and 6 inches in diameter were molded with a surrounding ring of 1:1 mortar. Before testing, the top and bottom surfaces were chipped off in order to eliminate the waterproofing effect of the rich surface layers. Plain 1:3 mortar at the age of 28 days under 30 pounds' pressure became damp after half an hour. Under 40 pounds' pressure the leakage amounted to 146 cubic centimeters after 24 hours' application. Specimens containing 5 and 10 per cent of oil No. 4923 remained perfectly tight under 40 pounds' pressure.

All permeability specimens made of gravel concrete and containing admixtures of oil have remained perfectly tight under 40 pounds' pressure per square inch. Some of the plain gravel specimens made to compare with the oil-mixed specimens leaked, while others remained tight. Broken-stone concrete made with a very inferior grade of crushed gneiss is not perfectly water-tight under pressure at early periods.

Even this inferior grade of concrete, however, tends to become much less permeable at later periods. The results of all permeability tests seem, however, to indicate that the resistance to water pressure is dependent more on the care used in proportioning and mixing the specimens than upon the addition of any extraneous waterproofing materials.

BOND TESTS.

To determine the adhesion of oil-mixed concrete to steel reinforcement, bond tests were made on specimens mixed in the proportions of 1:2:4 and containing various percentages of oil Rods 12 inches long were embedded in the center of cylinders 8 inches in diameter

and 8 inches long. The test consisted in pushing the rods through the concrete, and the point of failure was taken at the drop of the scale beam.

Two kinds of bars were used—plain and deformed. All specimens were tested at 28 days, and the results are plotted on figure 7. The bond strength is decreased, and the decrease depends directly on the quantity of oil in the mixture. It is evident that the bond between plain bars and concrete is so seriously affected by the mixture of oil that it would be inadvisable to use such a combination. The bond of deformed bars is not so seriously affected, but is somewhat decreased by the oil admixture.

SUMMARY OF CONCLUSIONS.

The following conclusions as to the effect of the oils used in cement and concrete may be drawn from the foregoing investigations:

(1) The *tensile strength* of 1:3 oil-mixed mortar is very little different from that of plain mortar, and shows a substantial gain in strength at 28 days and at 6 months over that at 7 days.

(2) The *times of initial and final set* are delayed by the addition of oil; 5 per cent of oil increases the time of initial set by 50 per cent and the time of final set by 47 per cent.

(3) The *crushing strength* of mortar and concrete is decreased by the addition of oil to the mix. Concrete with 10 per cent of oil has 75 per cent of the strength of plain concrete at 28 days. At the age of 1 year the crushing strength of 1:3 mortar suffers but little with the addition of oil in amounts up to 10 per cent.

(4) The *toughness* or resistance to impact is but slightly affected by the addition of oil in amounts up to about 10 per cent.

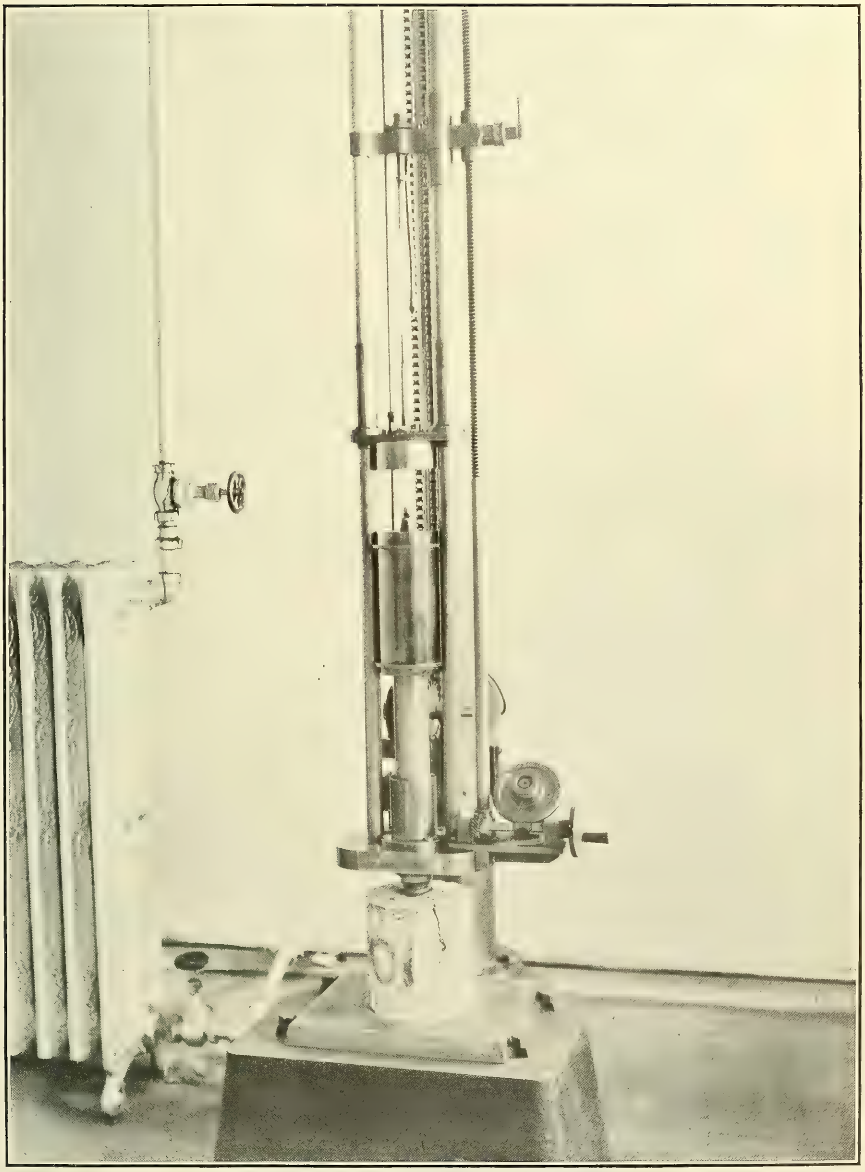
(5) The *stiffness* of oil-mixed concrete appears to be but little different from that of plain concrete.

(6) *Elasticity.*—Results of tests for permanent deformation indicate that no definite law is followed by oil-mixed concrete.

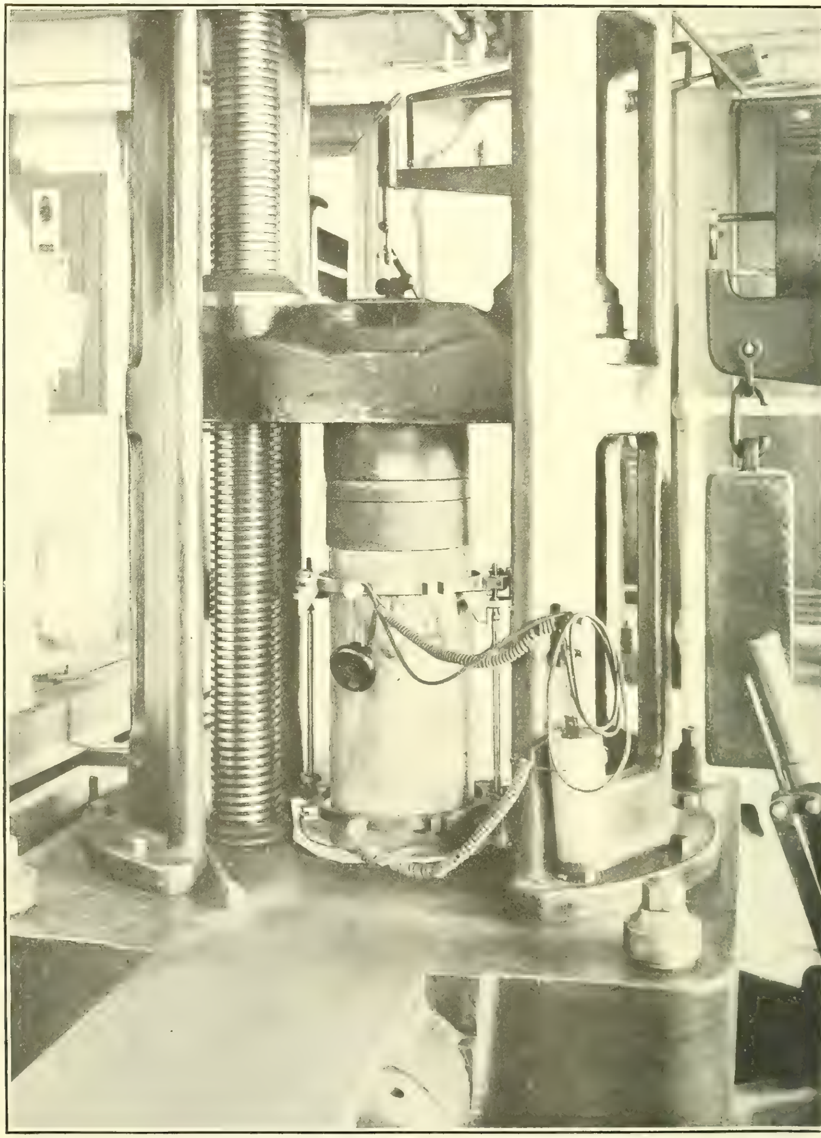
(7) *Absorption.*—Oil-mixed mortar and concrete containing 10 per cent of oil have very little absorption and under low pressures both are waterproof.

(8) *Permeability.*—While the laboratory tests to determine the waterproofing qualities of oil-cement concrete have not given uniform results, those made on oil-mixed cement mortar containing 10 per cent of oil have shown that such mortar is practically waterproof under pressures as high as 40 pounds per square inch. All the tests, whether in the laboratory or in construction work, indicate that oil-mixed mortar is very effective as a waterproofing agent under low pressures, when plastered on either side of a porous concrete or masonry wall.

(9) The *bond tests* show the inadvisability of using plain bar reinforcement with oil-concrete mixtures. The bond of deformed



IMPACT TEST ON OIL-MIXED CONCRETE.



TESTING THE STRENGTH AND ELASTICITY OF OIL-MIXED CONCRETE.

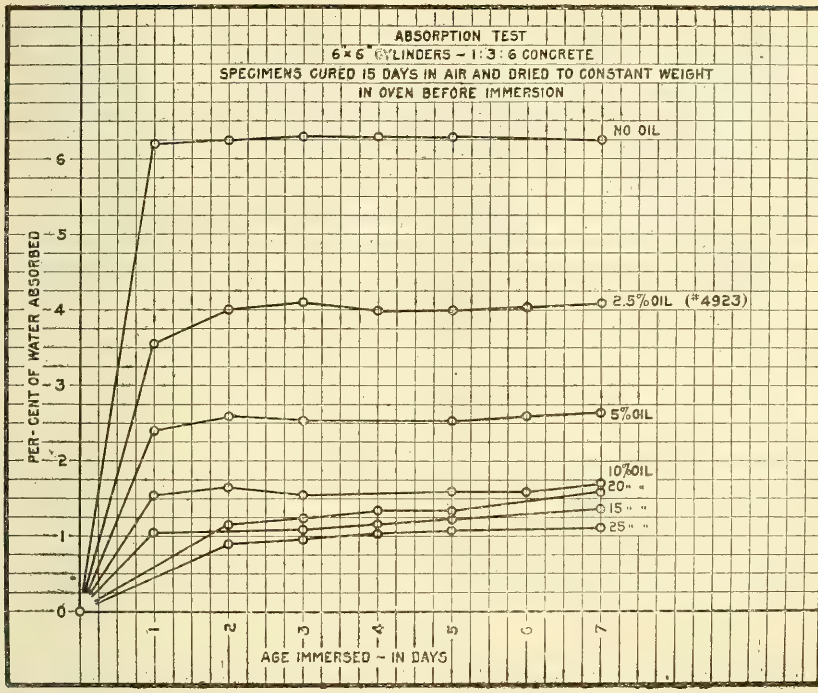


FIG. 6.—Absorption test.

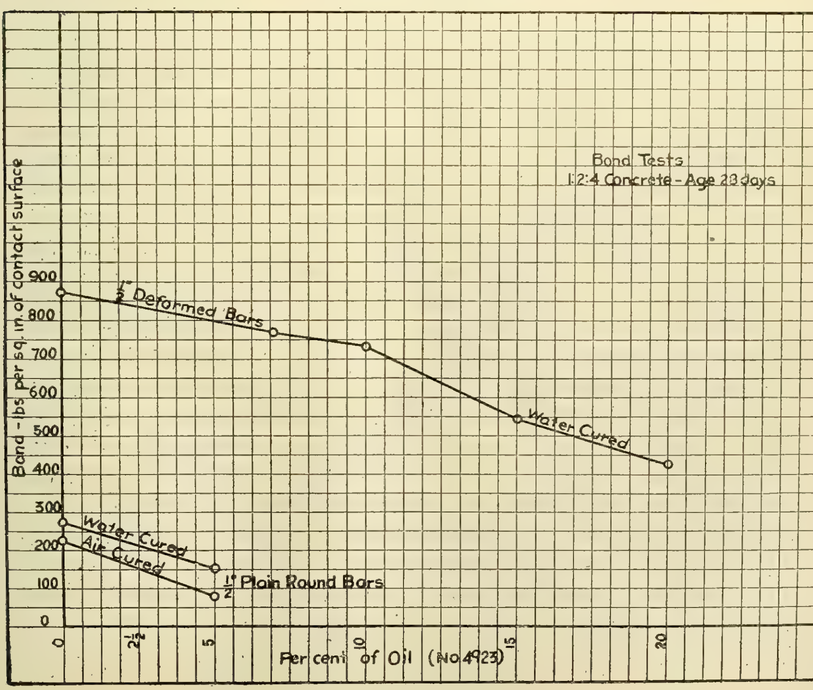


FIG. 7.—Bond tests.

bars is not seriously weakened by the addition of oil in amounts up to 10 per cent.

NOTE.—*A public patent has been granted for mixing oil with Portland cement concrete and hydraulic cements giving an alkaline reaction, and therefore anyone is at liberty to use this process without the payment of royalties.*

Caution.—The addition of any waterproofing or damp-proofing agent to cement mortar or concrete is valueless unless extreme care is exercised in proportioning, in mixing, and in placing the concrete.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 231

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER August 2, 1915.

RECENT STUDIES OF THE MEXICAN COTTON BOLL WEEVIL.

By B. R. Coad, *Entomological Assistant, Southern Field Crop Insect Investigations.*

CONTENTS.

INTRODUCTION.

The cotton season of 1913 was of great importance in the study of the boll weevil, *Anthonomus grandis* Boh., because of several opportune discoveries. Briefly, the events of the year were the discovery, by Mr. O. F. Cook, of the cotton boll weevil breeding upon a wild-cotton plant, *Thurberia thespesioides*, in Arizona; the establishment of breeding work at Victoria, Tex., for the purpose of studying any changes in the life history of the weevil; the discovery by the writer of important food adaptations of the weevil; explorations of southeastern Arizona by Dr. A. W. Morrill and Mr. W. D. Pierce in August, by Mr. Vernon Bailey later in the fall, and by Messrs.

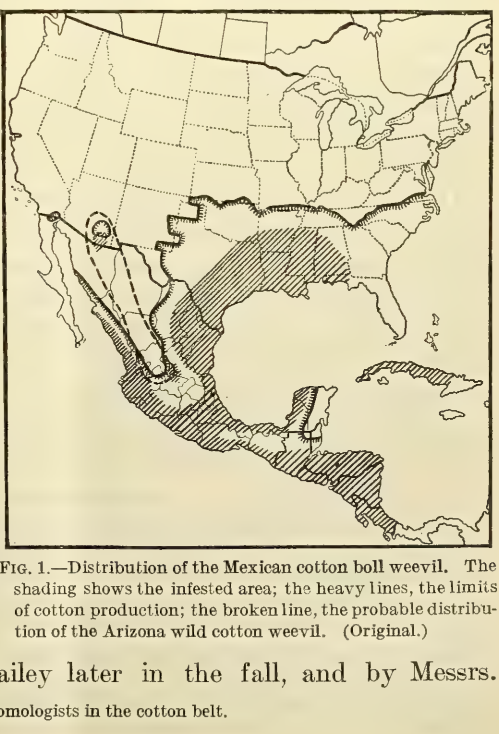

Fig. 1.—Distribution of the Mexican cotton boll weevil. The shading shows the infested area; the heavy lines, the limits of cotton production; the broken line, the probable distribution of the Arizona wild cotton weevil. (Original.)

Note.—This bulletin is of interest to entomologists in the cotton belt.

E. A. Schwarz and H. S. Barber in December, 1913. The results of the explorations and research work are quite fully treated in the body of this article.

Mr. Cook's announcement, which was published in February, 1913,[1] was followed by departmental press notices issued in October of the same year, and by a detailed article by Mr. W. D. Pierce describing the Arizona weevil as a new variety, *Anthonomus grandis* var. *thurberiæ*, issued November 10, 1913.[2]

A paper by the author on the food habits of the boll weevil in Texas has recently been published.[3]

This bulletin deals with a number of rather technical experiments and observations which have important bearings on the general boll-weevil problem. The principal matters dealt with are, first, the exact relation between the typical boll weevil, *Anthonomus grandis* Boh., and the form *A. grandis thurberiæ* Pierce, which has recently been found attacking a cottonlike plant in Arizona; and, second, the changes in the habits of the boll weevil which have taken place since it first entered the United States.

The importance of the first point mentioned lies in the fact that the western form of the boll weevil has adapted itself to life under extremely arid conditions, in which respect it differs conspicuously from the typical boll weevil. It therefore appears that the western weevil might thrive in the drier portions of Texas, where the typical weevil has not been able to establish itself, and thus reduce the production of cotton in a large area which has been depended upon to offset the loss caused by the boll weevil in more humid regions. Consequently, exact knowledge regarding the life history and habits of the Arizona weevil and its relation to the typical weevil are of importance.

The second matter dealt with in this bulletin, namely, the extent to which the boll weevil has changed its habits since it has been in the United States, is of great practical importance. More than 10 years ago a careful study of the habits of the typical boll weevil was made at Victoria, Tex. The present manuscript deals with similar studies just completed at the same place. These studies give an exact basis for estimating the extent of the departure from the original habits and serve to bring greater accuracy into predictions as to the ultimate nature of the boll-weevil problem in the United States.

DISTRIBUTION.

The discoveries of the year have added to the present knowledge of the distribution of the species. On the accompanying map (fig. 1)

[1] Cook, O. F. A wild host-plant of the boll weevil in Arizona. Science, n. s., v. 27, no. 946, p. 259-261, Feb. 14, 1913.

[2] Pierce, W. D. The occurrence of a cotton boll weevil in Arizona. U. S. Dept. Agr., Jour. Agr. Research, v. 1, no. 2, p. 89-96, Nov. 10, 1913.

[3] Coad, B. R. Feeding habits of the boll-weevil on plants other than cotton. U. S. Dept. Agr., Jour. Agr. Research, v. 2, no. 3, p. 235-245, June, 1914.

it will be seen that there are three apparent lines of distribution of the species, with Costa Rica as the apex. One line of distribution is along the Pacific slope, and although, according to present knowledge, the Arizona infestation is isolated from that of Sinaloa, Mexico, it is probable that the weevil occurs on *Thurberia thespesioides* in the mountains between these points. The Thurberia plant is known from Chihuahua and Guadalajara, Mexico, which latter locality is within a few miles of weevil-infested cotton.

The dispersion following the middle line is historic. Since 1880 this movement has been watched more or less thoroughly from Tamaulipas, Nueva Leon, and Coahuila, Mexico, until now (1914) it has reached the Georgia line (fig. 1).

The third line of distribution from Mexico through Yucatan to central Cuba is the cause of considerable speculation as to whether Cuba or the continent was the original source. There is also some speculation as to whether the Central American infestation furnished the nucleus for the dispersion or whether the weevil originated in southern Mexico and dispersed southward.

FOOD PLANTS.

The plant longest known as the food plant of the boll weevil is cotton, of which several species are now recorded as hosts—*Gossypium hirsutum*, *G. herbaceum*, *G. barbadense*, *G. brasiliense*, and also several Mexican species.

Mr. Cook's announcement added as a native food plant the so-called Arizona wild cotton, *Thurberia thespesioides*, which grows in a number of mountain ranges in southeastern Arizona, and also in parts of Mexico and probably New Mexico.

During the summer of 1913, following the discovery of a boll weevil feeding on cultivated *Hibiscus syriacus* at Victoria, Tex., the writer succeeded in rearing the species on buds of this plant, fed them for some time, and noted the partially complete development in buds of *Callirrhoë involucrata* and *C. pedata*, and kept them alive on *Sphæralcea lindheimeri* buds for a short period.

In the above series of experiments, by alternating foods it was found that the weevils have a wide range of hitherto unsuspected adaptability. This discovery makes the presence of malvaceous plants in the vicinity of cotton a possibly important factor in the ultimate control of the species. The greatest importance of this fact would arise in any attempted cessation of cotton planting as a control measure against the species.

CHOICE OF FOOD PLANT.

Two male and two female boll weevils reared from Thurberia buds imported from Arizona were placed with Thurberia buds and with cotton squares to test their food preference. They began feeding

immediately on both foods, but usually fed slightly more on the cotton squares than on the Thurberia buds. When egg deposition started the greater number of the eggs were deposited in cotton squares. These observations were continued for 15 days.

From these experiments it would appear that, when in captivity, weevils reared from Thurberia will feed on cotton squares just as readily as they will on Thurberia buds. The slightly greater amount of feeding on cotton squares in this experiment may or may not have any significance, and it was probably purely accidental.

These records made in the laboratory are in strong contrast with those made in the field. At Victoria the Thurberia plants under cultivation were within 50 feet of a small patch of cotton. This cotton was heavily infested by weevils throughout the season and not a boll was able to reach maturity. On the other hand, although the Thurberia plants were just as much exposed as the cotton, not a single indication of weevil work was found on the plants and not a weevil was found on them.

In Stone Cabin Canyon, Santa Rita Mountains, Ariz., Mr. W. D. Pierce was unable to find a weevil on cotton plants growing within 10 feet of Thurberia plants which were heavily infested with weevils. In December this same cotton was examined by Messrs. Schwarz and Barber and they were unable to find a sign of weevil work in the bolls.[1]

In this connection records made on the habits of larvæ of the cotton leafworm (*Alabama argillacea* Hübn.) are of interest. These larvæ are almost exclusively cotton feeders, but in the laboratory tests they fed on the Thurberia leaves as readily as on cotton when both were offered and were able to pupate and reach maturity on this food. In Stone Cabin Canyon this species was found feeding on Thurberia plants. The species was common on cotton at Tucson and Phoenix, Ariz. At Victoria, Tex., this species acted exactly as did the native weevils, with relation to the cotton and Thurberia patches. The cotton was heavily infested and only preserved from destruction by spraying, but not a single leafworm larva was ever found on the Thurberia plants. The moths were very numerous for a considerable period and eggs were abundant on the cotton, whereas careful examination failed to show an egg on the Thurberia plants.

CHARACTERISTICS OF THE ADULT.

DESCRIPTION OF THE SPECIES.

Owing to the recent studies on the variations of this species it becomes necessary to reconstruct the descriptions given by Boheman

[1] Experiments during 1914 in Arizona have proven that the Thurberia weevils will attack growing cotton.

and Dietz in order to include all variations. These descriptions are the joint work of Mr. W. D. Pierce and the writer:

Anthonomus grandis Boheman. [Redescribed.]—Stout, subovate to ovate, mahogany red to piceous and clothed with coarse baryta-yellow to raw sienna pubescence. Beak long, slender, shining, and sparsely pubescent at the base; more or less distinctly striate to about the middle; apical half finely and remotely punctured; the beak of the female is slightly longer and more slender than that of the male, more shining, and less coarsely punctured and striate. The female antennæ are inserted at about two-fifths of the distance from the apex of the beak to the eyes, while the male antennæ are inserted at one-third the distance from the apex. Antennæ slender; second joint of funicle longer than the third; joints 3–7 equal in length, but becoming gradually wider. The club may or may not be concolorous with the funicle and is more or less distinctly annulate. Head conical, pubescent, coarsely but remotely punctured, front foveate. Eyes moderately convex, posterior margin not free. Prothorax about one-third wider than long; base feebly bisinuate, posterior angles more or less rectangular; sides almost straight from base to middle, or slightly converging, strongly rounded in front; apex sometimes constricted and transversely impressed behind the anterior margin; surface moderately convex, densely and sometimes subconfluently punctured; punctures irregular in size, sometimes coarser about the sides; pubescence variable, often denser along the median line and on the sides. Scutellum variable. Elytra oblong, scarcely wider at the base than the prothorax; sides convex or subparallel for two-thirds of their length, thence gradually narrowed to and separately rounded at apex, leaving the pygidium moderately exposed; striæ deep, punctures large and approximate; interstices convex, rugulose, pubescence somewhat condensed in spots. Legs rather stout, femora clavate, anterior always strongly bidentate, inner tooth long and strong, outer one variable in shape but connected with former at base; middle and posterior femora unidentate or bidentate. Tibiæ moderately stout, more or less bisinuate internally; tarsi moderate, claws broad, blackish, and rather widely separated; tooth almost as long as claw. Length from 2.3 to 6.75 mm.; width from 1.1 to 3.6 mm.

Anthonomus grandis Boheman. [Typical variety.]—Stout, subovate, almost piceous, and clothed with coarse, baryta-yellow pubescence. Beak long, slender, shining, and sparsely pubescent at base; more or less distinctly striate to about the middle; apical half finely and remotely punctured; the beak of the female is slightly longer and more slender than that of the male, more shining, and less coarsely punctured and striate; the female antennæ are inserted at about three-fifths of the distance from the apex of the beak to the eyes, while the male antennæ are inserted at one-third of the distance from the apex. Antennæ slender, second joint of the funicle longer than the third; joints 3–7 equal in length, but becoming gradually wider; concolorous throughout, usually mahogany red; club rarely distinctly annulate and usually with only the faintest traces of whitish hairs on the apical margins of the first two joints. Head conical, pubescent, coarsely but remotely punctured, front foveate. Eyes moderately convex, posterior margin not free. Prothorax about one-third wider than long, base feebly bisinuate, posterior angles more or less rectangular; sides usually almost straight from base to middle, or slightly converging, strongly rounded in front; apex sometimes constricted and transversely impressed behind the anterior margin; surface moderately convex, densely and sometimes confluently punctured; punctures irregular in size, sometimes coarser on the sides; pubescence condensed in a sharply defined median vitta distinct from base to apex, also denser on sides. Scutellum narrow, elongate, convex, usually cylindrical, rounded oblong. Elytra oblong, scarcely wider at base than the prothorax; sides subparallel for two-thirds of their length, thence gradually narrowed to and separately rounded at apex, leaving the pygidium moderately exposed; striæ deep, punctures large and approximate; interstices convex, rugu-

lose, pubescence somewhat condensed in spots. Legs rather stout, femora clavate, anterior strongly bidentate, inner tooth long and strong, outer one variable but connected with former at base; middle femora unidentate in male, rarely with minute second tooth in female; posterior femora unidentate. Tibiæ moderately stout, more or less bisinuate internally; tarsi moderate, claws broad, blackish, and rather widely separated; tooth almost as long as claw. Length, from 2.3 to 6.75 mm.; width, from 1.1 to 3.6 mm.

Anthonomus grandis thurberiæ Pierce.—Stout, ovate, mahogany red, and clothed with coarse, raw sienna pubescence. Beak long, slender, shining, and sparsely pubescent at base; more or less distinctly striate to about the middle; apical half finely and remotely punctured; the beak of the female is slightly longer and more slender than that of the male, more shining and less coarsely punctured and striate; the female antennæ are inserted at about two-fifths of the distance from the apex of the beak to the eyes, while the male antennæ are inserted at one-third of the distance from the apex. Antennæ slender, second joint of funicle longer than the third; joints 3–7 equal in length but becoming gradually wider; the club piceous black, scape and funicle mahogany red; club with apical margins of the first two segments usually distinctly annulate with fine whitish hairs. Head conical, pubescent, coarsely but remotely punctured, front foveate. Eyes moderately convex, posterior margin not free. Prothorax about one-third wider than long; base bisinuate, posterior angles more or less rectangular; sides usually converging from near base to apical third and thence strongly convexly narrowed to apex; apex sometimes constricted and transversely impressed behind the apical margin; surface moderately convex, densely and sometimes subconfluently punctured, punctures irregular in size, sometimes coarser about the sides; pubescence evenly distributed; without sharply defined vittæ. Scutellum broad, subquadrate, rarely subtriangular, flattened. Elytra broad, scarcely wider at the base than the prothorax; sides slightly convex in basal two-thirds, thence strongly convexly narrowed and separately rounded at apex, leaving the pygidium moderately exposed; striæ deep, punctures large and approximate; interstices convex, rugulose, pubescence more regular but slightly condensed in spots. Legs rather stout, femora clavate, anterior always strongly bidentate, inner tooth long and strong, outer one variable in shape but connected with former at base; middle femora bidentate; posterior femora almost always unidentate. Tibiæ moderately stout, anterior and median bisinuate internally, posterior straight; tarsi moderate, claws broad, blackish, and rather widely separated, tooth almost as long as claw. Length, from 2.5 to 6.7 mm.; width, from 1.8 to 3.6 mm.

LONGEVITY OF ADULT WEEVILS.

Several series of experiments were conducted to determine the longevity of the weevils upon different foods. These experiments not only compare the two varieties of the weevil, but compare weevils from Tallulah, La., with those from Victoria, Tex.; various Malvaceæ with one another and with a diet of water only; different parts of the same plant; different seasons; and also the two sexes. The data obtained are presented in concise form in Table I.

The maximum record of longevity made in the 1913 work is based on a specimen of *Anthonomus grandis thurberiæ*, extracted from its hibernation cell August 27, after at least nine months in hibernation, which was still alive when the food supplies at Victoria gave out, October 29. This gives the maximum known period of hibernation as 270 days, and a total of over 333 days longevity. The maximum recorded length of life is 335 days for a hibernated weevil at Tallulah, La., in 1910.[1]

The maximum length of life of weevils after emergence from hibernation was 73 days for males and 71 days for females, both of which records are far below the highest previous records.

A true comparison of females fed on blooms of *Hibiscus syriacus* gives the average longevity of Arizona *A. g. thurberiæ* as 22.5 days, Texas *A. grandis* as 16 days, and Louisiana *A. grandis* as over 27 days.

The *grandis* males averaged 3.47 days on water, 5 days on *Sphæralcea lindheimeri*, 7.6 days on *Callirrhoë pedata*, 17.5 days on *Hibiscus syriacus*, 20 days on *Callirrhoë involucrata*, and 33.2 days on cotton, while the *thurberiæ* males averaged 27.6 days on *Hibiscus syriacus*.

The *grandis* females averaged 3.32 days on water, 5.4 days on both *Sphæralcea lindheimeri* and *Callirrhoë pedata*, 19.2 days on *Hibiscus syriacus*, and 34.3 days on cotton, while the *thurberiæ* females averaged 25.5 days on *Hibiscus syriacus*.

The greater longevity of weevils on the same food later in the season is very evident and is due to the advance of hibernation temperatures.

Although the records of life on cotton were shorter than those previously obtained when the totals are considered, it is noted that they agree quite well for any given season. It is evident that temperature and humidity exercise considerable control upon the length of life on any given food. The average longevity on cotton leaves was 11.9 days, on bolls 17.2 days, and on squares 42.1 days.

Adding these new records to those previously obtained 5,858 weevils fed on water only averaged 10.1 days; 16 weevils fed on cotton leaves only averaged 11.9 days; 226 weevils fed on miscellaneous malvaceous plants averaged 13.2 days; 92 weevils fed on cotton bolls averaged 19.9 days; 4,353 weevils fed on cotton foliage averaged 24.5 days; and 147 weevils fed on cotton squares averaged 59.5 days.

Comparing the sexes irrespective of food in all experiments hitherto conducted 4,226 males averaged 17.7 days, and 3,624 females averaged 18.5 days.

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[1] The longevity records of 1913 have been greatly exceeded during 1914 in experiments conducted at Washington, D. C. Weevils have been kept in a dormant state for over a year, and give promise of living considerably longer.

TABLE I.—*Duration of life of boll weevils.*

VARIETY GRANDIS, WITHOUT NORMAL FOOD.

Season.	Sustenance provided.	Males.				Females.				Both sexes.		Notes on weevils.
		Number.	Weevil[1] days.	Average longevity.	Maximum longevity.	Number.	Weevil[1] days.	Average longevity.	Maximum longevity.	Maximum longevity.	Average longevity.	
				Days.	*Days.*			*Days.*	*Days.*	*Days.*	*Days.*	
June 22–July 2	Moist sand	19	66	3.47	6	21	70	3.32	5	6	3.3	Bred.
May 13–May 28	*Sphæralcea lindheimeri*, buds and blooms.	3	22	7.3	9	3	30	10.0	15	15	8.6	Hibernated.
June 13–June 29	do	10	43	4.3	8	10	41	4.1	7	8	4.2	Bred.
Total on Sphæralcea.		13	65	5.0	9	13	71	5.4	15	15	5.2	
May 16–June 11	*Callirrhoë pedata*, buds and blooms.	4	56	14.0	26	4	41	10.2	18	26	12.1	Hibernated.
June 13–July 6	do	11	58	5.3	21	11	40	3.6	6	21	4.4	Bred.
Total on *Callirrhoë pedata*.		15	114	7.6	26	15	81	5.4	18	26	6.5	
May 13–June 2	*Callirrhoë involucrata*, buds and blooms.	1	20	20.0	20					20	20.0	Hibernated.
June 26–July 1	*Hibiscus syriacus*, buds	5	16	3.2	5	5	21	4.2	5	5	3.7	Bred.
June 26–Aug. 5	*Hibiscus syriacus*, blooms	4	120	30.0	40	2	32	16.0	28	40	25.3	Do.
Sept. 1–Oct. 13	do	2	+66	+33.0	+33	2	+54	+27.0	+33	+33	+30.0	Bred. Tallulah weevils.[2]
June 16–July 22	*Hibiscus syriacus*, buds, blooms, and fruit.	6	92	15.3	23	6	101	16.8	36	36	16.0	Collected.
July 16–July 28	do	6	91	15.1	26	6	140	23.3	43	43	19.2	Bred.
Aug. 28–Sept. 23	do	3	27	9.0	13	3	58	19.3	26	26	14.1	Do.
Sept. 9–Oct. 13	do	3	+97	+32.3	+34	4	+133	+33.3	+34	+34	+32.8	Do.[2]
Total on Hibiscus		29	+509	+17.5	40	28	+539	+19.2	43	43	+18.3	
Total all *grandis*	Abnormal malvaceous foods.	58	+708	+12.2	40	56	+691	+12.3	43	43	+12.2	

[1] "Weevil days" is the term applied to the sum of the time periods experienced by the various individuals during the course of the observations.
[2] These weevils were alive on October 13 when the food supply ran out.

VARIETY THURBERIÆ, WITHOUT NORMAL FOOD.

Season.	Sustenance provided.	Males.				Females.				Both sexes.		Notes on weevils.
		Number.	Weevil[1] days.	Average longevity.	Maximum longevity.	Number.	Weevil[1] days.	Average longevity.	Maximum longevity.	Maximum longevity.	Average longevity.	
				Days.	*Days.*			*Days.*	*Days.*	*Days.*	*Days.*	
Sept. 5-Oct. 18	*Hibiscus syriacus*, blooms	....	....	....	....	2	45	22.5	30	30	22.5	Bred.
Sept. 9-Oct. 13	*Hibiscus syriacus*, buds, blooms, and fruit.	5	+138	+27.6	+34	4	+108	+27.0	+34	+34	+27.3	Do.[2]
Total all *thurberiæ* on Hibiscus.		5	+138	+27.6	+34	6	+153	+25.5	+34	+34	+26.4	

VARIETY GRANDIS, WITH NORMAL FOOD.

Season.	Sustenance provided.	Males: Number.	Males: Weevil[1] days.	Males: Average longevity.	Males: Maximum longevity.	Females: Number.	Females: Weevil[1] days.	Females: Average longevity.	Females: Maximum longevity.	Both sexes: Maximum longevity.	Both sexes: Average longevity.	Notes on weevils.
June 9-July 24	Cotton, leaves	8	121	15.2	45	8	70	8.8	13	45	11.9	Bred.
June 18-July 20	Cotton, bolls	4	96	24.0	32	6	76	12.6	30	32	17.2	Do.
May 8-Aug. 1	Cotton, squares	10	497	49.7	73	13	556	42.8	71	73	45.6	Hibernated.
June 5-Oct. 10	do	9	318	35.3	52	32	1,325	41.4	74	74	40.0	Bred.
Total all *grandis* on cotton.		31	1,032	33.2	73	59	2,027	34.3	74	74	32.8	

[1] "Weevil days" is the term applied to the sum of the time periods experienced by the various individuals during the course of the observations.
[2] These weevils were alive on October 13 when the food supply ran out.

It is important to note that the maximum longevity on water was 6 days, on *Sphæralcea lindheimeri* 15 days, on *Callirrhoë involucrata* 20 days, on *C. pedata* 26 days, on *Hibiscus syriacus* 43+ days, and on cotton 74 days.

SEX OF ADULTS.

The material studied during the year was all sexed and the records have been tabulated to show the seasonal abundance and for comparison of the varieties (Table II).

TABLE II.—*Relative proportions of the sexes of boll weevils.*

Variety and description of material.	Male.		Female.	
	Number.	Per cent.	Number.	Per cent.
Grandis:				
Hibernated weevils	674	67.88	319	32.12
First generation collected	73	53.3	64	46.7
Collected in August	158	62.0	97	38.0
Bred	557	52.6	500	47.4
Total and average	1,462	59.8	980	40.2
Thurberiæ:				
Collected in August	21	51.3	20	48.7
Bred from Thurberia bolls in September	11	50.0	11	50.0
Bred from cotton in the fall	20	62.5	12	37.5
Extracted from Thurberia bolls, March, 1914	71	57.7	52	42.3
Total and average	123	56.9	95	43.1
Hybrids:				
♂ *Thurberiæ* × ♀ *grandis*	22	59.4	15	40.6
Second generation	21	42.0	29	58.0
Not positive crosses	135	51.0	130	49.0
♂ *Grandis* × ♀ *thurberiæ*	11	45.8	13	54.2
Second generation	15	57.7	11	42.3
Not positive crosses	20	51.3	19	48.7
Total and average	224	50.7	217	49.3
Total and average all weevils	1,809	58.3	1,292	41.7

Separating this material into hibernated and spring or summer bred weevils, there are in the hibernated material 777 males and 402 females, or 65.9 per cent males and 34.1 per cent females, while the spring and summer bred weevils numbered 1,032 males and 890 females, or 53.6 per cent males and 46.4 per cent females.

The total of all records to date gives 8,826 males and 6,710 females, or 56.7 per cent males and 43.3 per cent females.

It is noticeable that there is a larger percentage of females in the variety *thurberiæ* and in the hybrids than in the variety *grandis*.

REPRODUCTION.

RELATION OF FOOD TO COPULATION.

To test the period from emergence to copulation, a number of lots of males and females of the variety *A. grandis* were separated by sexes immediately after emergence and placed on either cotton

squares, leaves, or bolls. In each lot the weevils were paired off together for a few hours daily while under close observation. As soon as a pair copulated they were removed from the lot and the remainder tested until they either copulated or died. In this copulation series 23 pairs of weevils fed on squares, 2 pairs fed on bolls, and 1 pair fed on leaves copulated. These figures are of more value when taken in relation to the number of pairs of weevils that refused to copulate before death on the different foods. This relation is shown in Table III.

TABLE III.—*Relative proportion of boll weevils copulating on different foods.*

Food.	Number pairs of weevils carried to either copulation or death.	Number pairs copulated.	Percentage copulated.
			Per cent.
Cotton squares	38	23	60
Cotton bolls	8	2	25
Cotton leaves	8	1	12

From this table it is seen that copulation is unusual when the weevils are fed strictly on either cotton bolls or leaves.

AGE AT WHICH FERTILIZATION TAKES PLACE.

The length of the period before copulation depends in a large measure upon the temperature as well as upon the food. For square-fed weevils this period varied from 3 to 10 days, with a weighted average of 5.8 days.

In the series of boll-fed weevils only two records were made on this period. Both of these were in the latter part of June and were 6 and 8 days, respectively, giving an average of 7 days.

In the leaf-fed series only 1 pair copulated, and they gave a period of 5 days.

The records on boll-fed and leaf-fed weevils are too few in number to offer any comparison with the length of the period for square-fed weevils and serve only to emphasize the difficulty with which the life functions are performed on these unnatural foods.

The period from emergence to copulation was not determined exactly for the weevils fed only on buds and blooms of *Hibiscus syriacus*, but some idea of the period can be secured from the first date the weevils were observed in copula while making the daily examination. Two pairs of *A. g. thurberiæ* were first observed in copula in 6 and 14 days after emergence, while at the same time (September) two pairs of *A. grandis* were first observed in copula in 9 and 13 days after emergence. These records and the frequency with which the weevils were observed in copula later show that the proper element to stimulate copulation is present in the food.

PERIOD FROM FERTILIZATION TO OVIPOSITION.

The period from fertilization to oviposition was secured as a continuation of the experiments described under the period from emergence to copulation. After the females in this series copulated once they were placed on food and watched for the first egg deposited. In this manner the period was determined. In most cases the male was removed after the first fertilization, but in a few cases the male was placed with the female for a short period each day and the copulation noted. In this way as many as five copulations were noted for a female before a single egg was deposited. The periods determined are noted according to the food.

Weevils fed on cotton squares.—During June, July, and August this period was observed for 21 females fed only on squares. The period ranged from 1 to 7 days, with an average of 3.9 days.

Weevils fed on cotton bolls.—Three pairs of boll-fed weevils were observed from first copulation to oviposition. The period for these weevils ranged from 3 to 7 days, with an average of 5 days.

Weevils fed on cotton leaves.—Only one pair of weevils started copulating when fed only on cotton leaves from emergence. This female emerged July 7 and copulated the first time on July 11. She lived until July 24 and copulated 8 times in the interval. No eggs were laid.

PERIOD FROM EMERGENCE TO OVIPOSITION.

In the series of typical *grandis* the period from emergence to oviposition when on squares constantly varied from 3 days to 13 days, with an average of 6.1 days for the positive records.

With typical *thurberiæ* the three cases recorded ranged from 3 to 6 days, with an average of 4 days. These records are too few in number to allow a positive comparison with those for *grandis*, but the average is just about the same as for the latter during the same period (early September).

Two pairs of progeny of female *grandis* by male *thurberiæ* began to oviposit in 4 and 7 days each or an average of 5.5 days.

Two pairs of progeny of female *thurberiæ* by male *grandis* began to oviposit in 5 days each.

The period from emergence to oviposition was observed with six pairs of *grandis* fed only on buds and blooms of *Hibiscus syriacus* from maturity. Three of these pairs observed during early June varied from 5 to 6 days, and averaged 5.6 days. The other three pairs, observed during September, ranged from 11 to 18 days, with an average of 13.6 days.

This period was also observed with two pairs of *thurberiæ* on the same food. These began to oviposit in 12 and 16 days, or in an average of 14 days.

PERIOD FROM FIRST FEEDING ON SQUARES TO OVIPOSITION.

The period from first feeding on squares to oviposition is shown for hibernated *A. grandis* females in Table IV.

TABLE IV.—*Time from first feeding on squares to oviposition for hibernated females of A. grandis.*[1]

Collected, May—	First fed on squares, May—	First eggs deposited, May—	Period fed on squares to deposition.	Total period from first fed on leaves to deposition.
			Days.	*Days.*
8	14	22	8	14
8	14	19	5	11
8	15	20	5	12
8	17	19	2	11
10	24	25	1	15
Avg.			4.2	12.6
Max.			8	15
Min.			1	11

[1] These weevils were collected in the field before squares began to form and fed upon leaves until the dates noted above.

The weevils were collected in the field before any squares were formed and were fed only on cotton leaves until the dates given for placing on squares. It is seen that the period ranged from 1 to 8 days with an average of 4.2 days. An interesting point, however, is the fact that the time from the change from leaves to squares as food to the beginning of oviposition seems to vary inversely with the time fed on leaves. The totals of these two periods or, in other words, approximately the time from first feeding on the cotton plant to oviposition, are surprisingly similar. They vary from 11 to 15 days with an average of 12.6 days.

This period for female *thurberiæ* paired with male *grandis* was 12 and 15 days in the two cases tested in May and June. This gives an average of 13.5 days. In early September this period ranged from 2 to 5 days with an average of 3 days.

During the early part of September this period for typical *thurberiæ* varied from 1 to 3 days with an average of 2.2 days.

In all these series where female *thurberiæ* were used the individuals were extracted from their hibernation cells in Thurberia bolls and placed on cotton squares immediately.

The period from first feeding to oviposition of early hibernated females was observed in only one pair of weevils fed on the buds and blooms of *Callirrhoë pedata*. This female began depositing eggs 6 days after being placed on this food. As these weevils were collected during the early part of May they had probably fed very little, if at all, on cotton.

DURATION OF FERTILITY AND FECUNDITY.

Many experiments were conducted to test the duration of fertility and the fecundity of the various types of weevils. With *A. grandis* special experiments on this question were conducted in addition to the regular breeding series. Rather thorough data were obtained on the variety *thurberiæ* and the various crosses in the different breeding series of these.

Fecundity of females of A. grandis in copula only once.—The previous results on the exact duration of the fertility of females after copulation were very indefinite and there were no records of the fecundity resulting from only one copulation. In the course of the past summer's investigations the writer was able to secure considerable information on this point.

Eleven females were separated from the males immediately after emergence and only returned to them about 6 hours each day when under close observation. In this manner the first copulation of each female was determined and she was then placed alone on squares to test her fecundity with no more chances for fertilization. Of the 11 females so treated, five were fertile, four were infertile but deposited eggs, and two failed to deposit any eggs. Of the two that did not deposit eggs, one was in copula 25 minutes and the other 10 minutes. Each of these lived a short time and then died. The fecundity tests of the remainder gave the results found tabulated in Tables V and VI.

TABLE V.—*Fecundity of females of A. grandis in copula only one time and rendered fertile in that time.*

Duration of fertility.	Time in copula.	Oviposition.			Total eggs.	Eggs deposited.		Eggs per day.	
		Started.	Ended.	Period.		Externally.	Normally.	Average.	Maximum.
	Minutes.			*Days.*					
To end of oviposition	24	June 28	Aug. 7	41	348	0	348	8.5	17
To Aug. 10	[1] 45	...do....	Aug. 27	61	456	9	447	7.4	21
To end of oviposition	26	June 30	July 18	19	87	0	87	4.6	7
Do	[2] 31	July 12	Aug. 12	32	237	0	237	7.4	17
Do	29	Aug. 9	Sept. 4	27	32	0	32	1.2	3
Total	155			180	1,160	9	1,151		
Average	31			36	235				
Weighted average								6.4	
Maximum	45			61	456	9	447	8.5	21
Minimum	24			19	32	0	32	1.2	3

[1] Copulated twice (22 and 23 minutes respectively) with interval of 12.5 minutes between copulations.
[2] Copulated four times (7, 4, 2, and 18 minutes respectively) between 10:04 a. m. and 11:18 a. m. Remainder of the weevils were in copula only one time. These copulations were with so very little time between them that they were considered as one fertilization.

TABLE VI.—*Fecundity of females of A. grandis in copula only one time and not fertilized.*

Total, average, etc.	Time in copula.	Oviposition.			Total eggs.	Eggs deposited.		Eggs per day.		Time from last egg to death.
		Started.	Ended.	Period.		Externally.	Normally.	Average.	Maximum.	
	Min.			*Days.*						*Days.*
....	3	June 29	June 29	1	1	0	1	1	1	4
....	7.5	June 30	Aug. 26	58	67	51	16	1.1	6	1
....	19	July 1	July 1	1	3	0	3	3	3	8
....	37.5	...do....	July 3	3	3	0	3	1	1	35
Total...	67.0	....	....	63	74	51	23	....	....	48
Average.......	16.7	....	....	15.7	18.5	....	....	....	....	12
Weighted average........	....	....	....	....	....	....	....	1.1	....	....
Maximum....	37.5	....	....	58	67	51	16	3	6	35
Minimum.....	3	....	....	1	1	0	1	1	1	1

From Table V it is seen that the greatest fertility was with the longest period of copulation (45 minutes). Beyond this there seems to be very little relation between the time in copula and the resulting degree of fertility. In the infertile females it is seen that periods of 25 and 37.5 minutes in copula still failed to result in fertility.

The total eggs deposited by the fertile females ranged from 32 to 456 with an average of 235 each for the five females. This average is quite high, even in comparison with females having males present throughout life. The infertile females deposited from 1 to 67 eggs, with only one depositing more than 3 eggs.

The period of fertility of the fertile females ranged from 19 to 44 days with an average of 32.6 days. The average eggs per day ranged from 1.2 to 8.5 with a weighted average of 6.4. This is a rather high average when compared with the results secured in other deposition series.

A comparison of these results seems to indicate that the time in copula has very little influence on the resulting fertility of the female. One female was not rendered fertile during 37.5 minutes of copulation while four others were fertilized in less than this time. The shortest time in copula which resulted in fertility of the female was 24 minutes, but the writer thinks that this is not significant.

The high average of the eggs deposited by the females fertilized only once would seem to indicate that one fertilization is sufficient to produce the maximum fecundity of the female. While this may be true in certain rare instances, the writer believes that such cases will be very rare. In a different breeding series a few females were allowed to deposit eggs from one fertilization until they stopped deposition, then males were added and in every case the females began depositing again and continued for some time. The female with the highest deposition record in the one fertilization series discussed above quite evidently reached the limit of her fertility 17 days before death and she deposited 9 infertile eggs in this period.

From this evidence it seems clear that one copulation will often result in fertilization, but will not usually suffice for complete fecundity of the female.

Fecundity of females of A. grandis with complete record on copulation.—Since very little was known concerning the exact number of times a single female will copulate in the course of her life an attempt was made to secure some information on this point.

Nine females were separated from the males immediately after emergence and each was fed separately throughout life. A male was allotted to each female and each day the different pairs were placed together in dry glass tubes for a short time while under close observation and given a chance to copulate. The period spent in copula was noted each time and in this manner a complete record of the copulations of each female was secured. During the remainder of the day the females were kept on fresh squares and the daily egg deposition noted. The results secured in this series are shown in Table VII.

TABLE VII.—*Fecundity of females of A. grandis with complete record of time in copula.*

Total, average, etc.	Times in copula.	Total time in copula.	Average time per copula.	Oviposition.			Total number eggs.	Eggs deposited externally.	Average number eggs per day.	Maximum number eggs per day.
				Started.	Ended.	Period.				
		Min.	*Min.*			*Days.*				
....	22	490.5	22.3	July 2	July 29	28	204	0	7.3	13
....	30	667.5	22.2	July 4	Aug. 9	37	217	0	5.8	18
....	33	786.5	23.8	...do.....	Aug. 24	52	302	4	5.8	15
....	27	689.0	25.5	July 5	Aug. 4	31	112	0	3.6	10
....	29	650.5	22.4	July 6	Aug. 12	38	126	2	3.3	10
....	24	563.0	23.4	July 7	Aug. 6	31	126	1	4.0	10
....	18	369.0	20.5	...do.....	Aug. 7	32	208	0	6.5	14
....	13	291.5	22.4	July 9	Aug. 5	28	65	0	2.3	10
....	9	196.0	21.7	July 11	Aug. 27	17	32	0	1.9	5
Total............	205	4,703.5	....	....	....	294	1,392	7	......	......
Average..............	22.7	522.6	22.9	....	....	32.7	154.7	......	......	......
Weighted average	......	......	......	....	....	......	......	......	4.7	......
Maximum............	33	786.5	25.5	....	....	52	302	4	7.3	18
Minimum............	9	196.0	20.5	....	....	17	32	0	1.9	5

The number of times a single female will copulate was found to be much higher than was anticipated. With these 9 females the number varied from 9 to 33, with 6 females copulating more than 20 times. The average per female was nearly 23 times.

In spite of the great number of copulations the number of eggs deposited by these females was not high in comparison with other series. It may be that the fact that the females were of necessity removed from their food for from 1 to 2 hours daily while with the males had some effect on the egg deposition. The total number of eggs per female varied from 32 to 302, with an average of 154.7 eggs per female. This average is considerably lower than that for the females fertilized only once The average number of eggs per female per day was 4.7, which is also lower than the average for the once fertilized females.

When the male and female weevils were placed together in the dry tubes daily they very rarely failed to copulate. They would usually unite within a few minutes after being being placed in the tube and it was very rarely that they copulated at all if they did not start almost immediately after having the opportunity. It was extremely rare for the two sexes to remain together without copulation for a half hour and then unite.

The various breeding series in which one pair of weevils were together on squares were examined only once daily and many pairs were found in copula day after day when making these daily examinations. In the field it was very noticeable that a pair usually united as soon as they were placed together on a plant. When weevils are collected in the field and placed in a tube it is the common occurrence for many pairs to unite as soon as dropped in the tube. Hence it seems probable that it is normal for a single female to be in copula many times and for the weevils to copulate almost whenever they meet in the course of their travels over the plants.

Three females deposited a total of 7 eggs externally. These eggs were deposited during the days when the same females deposited other eggs normally. As the females were certainly fertile, owing to the almost daily copulations, this shows that external deposition of eggs may be due to some cause other than infertility. The eggs deposited externally by these females were tested for viability and all hatched.

Fecundity of A. grandis females after hibernating.—Twelve females were collected in the field at Victoria, Tex., May 8 to 10, shortly after emergence from hibernation, and fed on cotton leaves until squares became available. Then each was placed with a male and given fresh squares daily for oviposition. These females were all observed until their normal death. The results secured are shown in Table VIII:

TABLE VIII.—*Fecundity of females of A. grandis after hibernating.*

Number of females.	Total eggs laid.	Average eggs per female.	Approximate oviposition period per female.	Eggs per day.	
				Average.	Maximum.
			Days.		
2	144	72	12	6.0	14
2	673	336.5	32	10.5	[1] 20
1	302	302	53	5.7	12
2	336	168	25	6.7	11
2	715	357.5	55	6.5	12
2	701	350.5	46	7.6	19
1	100	100	13	7.6	11
Total, 12	2,971		406		
Average		247.6	33.8		
Weighted average				7.3	
Maximum		358	55	10.5	20
Minimum		72	12	5.7	11

[1] The 2 females in this lot deposited 39 eggs in 1 day. Therefore one of them laid at least 20 eggs.

Unfortunately 10 of these females were placed 2 to a breeding cage, and consequently the records for each of these cages give the activities of 2 females instead of 1. Therefore complete individual records of these females can not be given.

The total number of eggs deposited by these weevils is very high. The average per female in the different lots ranged from 72 to 358 eggs. The average for the 12 females is 247.6 eggs. These averages are considerably higher than those of the reared weevils of the later generations. It was previously supposed that, owing to the vitality used in passing the winter, hibernated females would deposit less eggs than weevils emerged during the summer, but this is shown not to be the case.

The previously recorded maximum number of eggs deposited by a single female was 304. It is of considerable interest to note that 6 out of these 12 hibernated females evidently exceeded that number. The average number of eggs per day ranged from 5.7 to 10.5, with an average of 7.3. This also is greater than the average of any of the later generations.

Fecundity of summer-reared weevils.—Although the greater part of the females used in the various generation series of *A. grandis* during the season were not allowed to complete oviposition, 7 of them were continued to completion. The activities of these females are shown in Table IX.

TABLE IX.—*Fecundity of females of A. grandis in various breeding series throughout the season.*

Source of weevils.	Oviposition—			Total eggs.	Eggs per day.	
	Started.	Ended.	Period.		Average.	Maximum.
			Days.			
First generation adults	June 18	July 12	25	205	8.2	14
Third generation adults	July 26	Sept. 30	67	141	2.1	10
Do	...do	Aug. 10	16	83	5.2	12
Do	...do	Sept. 23	60	205	3.4	12
Last adults of first generation	Aug. 3	Sept. 30	59	233	3.9	11
Fourth generation adults	Aug. 18	...do	44	153	3.5	12
Do	...do	...do	44	45	1.0	5
Total				1,065		
Average			45	152.1		
Weighted average					3.3	
Maximum			67	233	8.2	14
Minimum			16	45	1.0	5

Considering the fact that these females were with males constantly, were given fresh squares daily and were less disturbed than any others, it is surprising that their oviposition was so low. The maximum did not equal the average of the once copulated weevils and the average is nearly 100 less than the average for the hibernated females.

The average number of eggs per day ranged from 1 to 8.2, with an average of 3.3 eggs. This is also much less than the average for either the hibernated or once copulated weevils. The maximum number of eggs per day ranged from 5 to 14. In fact these weevils showed a surprisingly low degree of fertility in all points.

Fecundity of females of A. grandis in experiments not continued to completion.—Many of the females in the various *grandis* generation series were allowed to oviposit only a short time and then stopped because of lack of squares. Some interesting data were secured from some of these weevils, as is shown in Table X.

TABLE X.—*Fecundity of females of A. grandis in experiments not continued to completion.*

Oviposition started.	Experiment closed.	Oviposition.	Total eggs.	Eggs per day.	
				Average.	Maximum.
		Days.			
June 16	June 20	5	20	5.0	7
June 17	July 2	16	147	9.2	15
Do	July 11	25	318	12.7	26
July 7	July 12	6	45	7.5	11
Do	...do	6	99	16.5	21
July 9	...do	4	31	7.7	11
Sept. 8	Sept. 21	14	53	3.7	8
Sept. 9	...do	13	73	5.6	10
Maximum				16.5	26
Minimum				3.7	7

This information is of principal value in giving maximum and minimum records. One female in this lot gave the season's maximum record for eggs deposited in one day. This was 26 eggs. Incidentally this is the highest number of eggs deposited by a single female in one day on record. This female was allowed to continue deposition only 25 days, but in this time she deposited a total of 318 eggs, or an average of 12.7 per day.

Fecundity of typical A. g. thurberiæ fed on cotton squares.—Three pairs of pure *thurberiæ* were mated on cotton squares in June, but for some reason only one female deposited any eggs. This one deposited 7 eggs with a maximum of 4 in 1 day and an average of 0.3 per day. These eggs were probably all fertile, as most of them, at least, hatched. It is very hard to account for the fact that two of these females laid no eggs and the other deposited so few. The females of *thurberiæ* placed with *grandis* males at this same time deposited a normal number of eggs.

The fall series of pure *thurberiæ* mated on cotton squares gave much better results, as is shown in Table XI.

TABLE XI.—*Fecundity of typical A. g. thurberiæ.*

Number of females.	Oviposition.			Total eggs.	Eggs per day.		Mean temperature for period.
	Started.	Ended.	Period.		Average.	Maximum.	
			Days.				*° F.*
1[1]	Sept. 7	Sept. 7	1	1	1.0	1	
1	Sept. 3	Oct. 6	34	173	5.1	17	77.6
1	Sept. 2	Oct. 1	30	73	2.4	11	77.3
1	...do....	Oct. 2	31	90	3.0	8	77.4
1	Sept. 4	Oct. 6	33	76	2.3	8	77.4
Total			128	412			
Average			32	103			
Weighted average					3.2		77.4
Maximum			34	173	5.1	17	
Minimum			30	73	2.3	8	

[1] Owing to the fact that this female deposited only one egg, the record is not included in the averages and summary given.

Five pairs were mated, and while four females deposited fairly well, the other deposited only one egg and is not considered in the following discussion. The total number of eggs deposited by these females ranged from 73 to 173, with an average of 103. The average per day ranged from 2.3 to 5.1, with an average of 3.2, and the maximum in one day was 17. All of these records are very low in comparison with the results of practically all other series. On the other hand, the *thurberiæ* females mated with *grandis* males at this time gave better deposition records.

Results of the mating of male of A. g. thurberiæ and female of A. grandis.—In June two hibernated *grandis* females collected in the field were placed with male *thurberiæ* on cotton squares. As these females were undoubtedly fertilized by *grandis* males before being isolated, this series did not result in positive proof of cross breeding, but, as the weevils copulated freely, the later progeny were quite probably hybrids.

These two females deposited 192 and 387 eggs, respectively, with an average of 7.1 and 7.9 each per day. The average total number of eggs per female was 289.5 and the daily average was 7.6. The maximum number of eggs per day was 16 for each female. On the whole this fecundity is quite high and the females were surely refertilized by the new type of males.

In September three known infertile females of *grandis* were mated with male *thurberiæ* on cotton squares immediately after emergence. This resulted in the positive crossing of the two. The results of these matings are shown in Table XII.

TABLE XII.—*Fecundity of positive crosses of male of thurberiæ and female of grandis.*

Total, average, etc.	Number of females.	Oviposition.			Total eggs.	Eggs per day.		Average temperature for period.
		Started.	Ended.	Period.		Average.	Maximum.	
				Days.				°*F.*
	1	Sept. 7	Oct. 24	48	115	2.4	7	74.4
	1	Sept. 4	Sept. 11	38	43	1.1	4	77.8
	1	Sept. 5	Sept. 17	13	69	5.3	8	78.9
Total	3			99	227			
Average				33	75.6			
Weighted average						2.3		76.3
Maximum				48	115	5.3	8	
Minimum				13	43	1.1	4	

The total oviposition of these females was surprisingly low, ranging from 43 to 115 and averaging 75.6 eggs per female. The average number of eggs per day was only 2.3 and the maximum number of eggs in one day was only 8.

Results of the mating of male of A. grandis and female of A. g. thurberiæ.—In June two of the female *thurberiæ* received were mated on cotton squares with male *grandis* collected in the field. As these females had been shipped with *thurberiæ* males, there was a possibility of their being fertile at the time of placing with *grandis* males, but refertilization probably occurred.

These females deposited 115 and 130 eggs respectively, with an average of 122.5 each. The average per day was 3.4 and 3.9 eggs, making an average of 3.6 each for the two females. The maximum in one day was 7 eggs.

In the fall three females of *thurberiæ* reared from Thurberia bolls received from Arizona were mated with the males of *grandis* on cotton squares immediately after emergence. Thus positive crosses were secured. The activities of these females are shown in Table XIII.

TABLE XIII.—*Fecundity of positive crosses of female of thurberiæ by male of grandis.*

Total, average, etc.	Number of females.	Oviposition.			Total eggs.	Eggs per day.		Mean temperature for period.
		Started.	Ended.	Period.		Average.	Maximum.	
				Days.				°*F.*
	1	Sept. 6	Oct. 27	52	95	1.8	8	73.9
	1	Sept. 3	Oct. 2	30	146	4.8	13	77.3
	1	...do....	Oct. 8	36	102	3.0	8	80.2
Total	3			118	343			
Average				39.3	114.3			
Weighted average						2.9		76.7
Maximum				52	146	4.8	13	
Minimum				30	95	1.8	8	

Here again the total eggs deposited was quite low and the average eggs per day was likewise low. However the fecundity was quite high enough to equal many of the *grandis* females depositing at the same time; consequently there seems little reason to believe that the fecundity of *thurberiæ* is less than that of *grandis*.

Results of the mating of progeny of male of thurberiæ and female of grandis.—In the latter part of June three pairs of weevils reared from eggs deposited by doubtful crosses of male *thurberiæ* and female *grandis* were mated on cotton squares. Two pairs were placed together in one jar and allowed to continue deposition until the normal cessation. These two females deposited a total of 100 eggs and averaged 4.3 per day. The maximum number in one day was 14 eggs. The other female was allowed to continue oviposition for 18 days, and in this time she deposited a total of 143 eggs at the rate of 8 eggs per day. The maximum number for one day was 15 eggs.

Results of the mating of progeny of male of grandis and female of thurberiæ.—In July two pairs of weevils reared from eggs deposited by doubtful crosses of male *grandis* and female *thurberiæ* were mated on cotton squares. Owing to the shortage of squares these weevils were stopped after having deposited for 17 and 5 days, respectively. The first female deposited a total of 131 eggs at the rate of 7.3 per day, with a daily maximum of 15, and the second deposited 48 eggs at the rate of 9.6 per day, with a daily maximum of 14.

MAXIMUM NUMBER OF EGGS PER DAY.

The maximum number of eggs deposited in 1 day by any female was 26. A first generation *grandis* female emerging June 8 deposited this number of eggs in cotton squares July 2. The mean temperature was 81.1° F. and the mean humidity was 68 per cent for the oviposition day involved. The previous record for 1 day's deposition (20 eggs) was exceeded many times by quite a number of females.

The maximum number of eggs deposited by typical *thurberiæ* on cotton squares was 17. This number was deposited September 8 at a mean temperature of 86.4° and a mean humidity of 78 per cent for the oviposition day.

The maximum for the mating of infertile female *thurberiæ* and male *grandis* was 13 eggs. This number was deposited September 10 at a mean temperature of 81.4° and a mean humidity of 83.5 per cent for the oviposition day.

The maximum for the mating of infertile female *grandis* and male *thurberiæ* was 8 eggs. This number was deposited September 16 at a mean temperature of 76° and a mean humidity of 77.5 per cent for the oviposition day.

The maximum number for females fed only on buds and blooms of *Callirrhoë involucrata* was 3 eggs.

The maximum for females fed only on the buds and blooms of *Hibiscus syriacus* was 8 eggs.

RATE OF OVIPOSITION.

The daily rate of oviposition has already been shown in the discussion of the general fecundity of the weevils, but the rate by fractions of the oviposition period of the different females is also of interest. In the following studies the oviposition period of each female has been divided into thirds and the results tabulated accordingly. This is shown in Table XIV.

TABLE XIV.—*Rate of oviposition of the boll weevil obtained in all experiments.*

Nature of weevils.	Number of females.	Season.	Rate of oviposition.					
			First third of period.		Middle third of period.		Last third of period.	
			Total eggs.	Daily average.	Total eggs.	Daily average.	Total eggs.	Daily average.
Hibernated *grandis* females.	2	May to July	136	6.5	161	7.3	105	4.6
Once fertilized *grandis* females.	5	June to September	521	9.0	484	8.2	155	2.5
Grandis females with a complete record on copulation.	9	July to August	492	5.2	590	6.0	310	3.0
Various breeding series of *grandis*.	6	June to September	415	4.7	386	4.3	219	2.3
Pure *thurberiæ*	4	September to October.	234	5.5	130	3.1	46	1.0
Positive crosses of male *thurberiæ* and female *grandis*.	3	do	77	2.4	83	2.5	67	2.0
Doubtful crosses of male *thurberiæ* and female *grandis*.	2	May to July	142	5.6	283	9.5	189	7.2
Positive crosses of male *grandis* and female *thurberiæ*.	3	September to October.	155	4.0	127	3.2	61	1.5
Doubtful crosses of male *grandis* and female *thurberiæ*.	2	June to July	81	3.9	101	4.4	63	2.7
Total			2,253		2,345		1,215	
Average				5.2		5.4		2.9

Here it is seen that the maximum rate of oviposition in the average of all series is reached in the middle period and the minimum is in the last period. However, there are several exceptions to this in the averages of the different types of females. It is interesting to compare the results of the spring and fall series. In the former the average of the middle third is much higher than the first and the last is only slightly lower, while in the fall series there is generally a great decrease in the latter part of the period. This difference is of course due to the temperature increasing from spring to summer and decreasing in the fall.

IS THE FECUNDITY OF THE WEEVIL DECREASING?

In previous bulletins on the boll weevil this question was put, but not answered because of insufficient data. A comparison of the total number of eggs laid by weevils at Victoria and the rate per day for 1902 to 1904 with 1913 gives the following results:

In 1902 to 1904 at Victoria 132 weevils laid 11,863 eggs at the rate of 89 eggs each, or 2.8 eggs each per day with a maximum of 135 eggs per female. In 1913 at Victoria 19 weevils in various seasons laid 4,036 eggs at the rate of 212 eggs each, or 5.9 eggs each per day with a maximum of 358 eggs. In one of the fecundity series in 1913 a female *grandis* exceeded even this maximum and laid a total of 456 eggs. This evidence seems to indicate that if there has been any change in the fecundity of the species it is in the nature of an increase rather than a decrease.

OVIPOSITION PERIOD.

During the summer a total of 47 females were observed through the complete oviposition period. The results of these observations are summarized in Table XV.

TABLE XV.—*Oviposition period of the boll weevil obtained in all experiments.*

Source of weevils.	Season.	Number of females.	Maximum period.	Minimum period.	Average period.
			Days.	*Days.*	*Days.*
Once fertilized *grandis* females	June to September	5	61	19	36
Grandis females with complete record on copulation.	July to August	9	52	17	32.7
Hibernated *grandis* females	May to July	12	55	12	33.8
First generation *grandis*	June to July	1			25
Third generation *grandis*	July to September	3	67	16	47.7
Last of first generation *grandis*	August to September	1			59
Fourth generation *grandis*	do	2	44	44	44
Pure *thurberiæ*	September to October	4	34	30	32
Positive crosses of male *thurberiæ* and female *grandis*.	do	3	48	13	33
Doubtful crosses of male *thurberiæ* and female *grandis*.	May to June	2	49	27	38
Positive crosses of male *grandis* and female *thurberiæ*.	September to October	3	52	30	39.3
Doubtful crosses of male *grandis* and female *thurberiæ*.	June to July	2	38	29	33.5
Total		47			
Weighted average					35.8
Maximum			67		
Minimum				12	

Here it is seen that the period ranged from 12 to 67 days with an average of 35.8 days for all females. The number of females of the different classes is too small to permit anything like an accurate comparison of results. While the pure *thurberiæ* and the crosses containing females of this variety averaged a slightly shorter time for the period than the native *grandis*, this difference is not great enough to indicate that there is any special significance in it.

Although the 1913 records on the oviposition period did not in any case approach the maximum recorded period, the average length was almost 5 days longer than the average of all previously recorded experiments.

EXTERNAL DEPOSITION OF EGGS.

In all types of breeding series and at all times during the season females were observed to deposit eggs externally. Usually, when the eggs were deposited externally, the female was either infertile or about through ovipositing but not infrequently fertile eggs were deposited externally by females on the same day they deposited a number normally. A few observations were made of fertile females depositing eggs in empty glass tubes. Every time this happened the female would turn and immediately eat the egg. This habit of eating eggs deposited externally was observed many times and undoubtedly greatly reduced the number found.

The eggs deposited externally were found in all manner of positions on the calyx and bracts of squares, some even being found on the outside of the bracts. When covered with a moist cloth and placed on damp sand several of the eggs hatched. In one case an egg hatched within 24 hours after deposition and two others hatched within 48 hours. As eggs in squares at this time were taking 3 and 4 days to hatch it seems evident that the period for those deposited externally was shortened by the greater exposure to the heat at the time. The tissue of the squares surrounding those deposited normally probably reduces the temperature affecting the eggs.

A number of larvæ were observed after hatching from eggs deposited externally. Although several of these larvæ were very near punctures in the square not one was observed to make its way into the square. They all moved around considerably but died within about one day after hatching. In one case a larva hatched from an egg placed about half inside a puncture and died without entering the square.

Some of these larvæ were taken immediately after hatching and placed in an incision in a square. These larvæ lived and matured. One larva hatched from an egg deposited on the petal of a Hibiscus bloom was placed in an opening in a Hibiscus bud and reached pupation safely.

Many of the eggs deposited externally were not observed for hatching, so no record can be given on the percentage of these eggs that were infertile, but in one series of females that were depositing fertile eggs all eggs deposited externally were kept and records made on the number hatching. A total of 20 eggs was deposited externally in this series and, of these, 3 hatched, or only 15 per cent. From this and the general observations made during the season it seems evident that by far the greater part of the eggs deposited externally are infertile, but occasionally fertile eggs are deposited in this manner.

NUMBER OF EGGS DEPOSITED FIRST DAY OF OVIPOSITION.

The number of eggs deposited the first day of oviposition by each female in all series varied from 1 to 12 with an average of 3 eggs for the 58 females observed during the season.

For typical *grandis* the number varied from 1 to 12 with an average of 3 eggs.

For typical *thurberiæ* the number varied from 1 to 10 with an average of 3.4 eggs.

The number for the mating of infertile female *thurberiæ* and male *grandis* varied from 1 to 2 with an average of 1.6 eggs. The number for the mating of infertile female *grandis* and male *thurberiæ* varied from 1 to 4 with an average of 2 eggs.

PERIOD FROM THE DEPOSITION OF LAST EGG TO DEATH.

The period from the deposition of the last egg to the death of the female in all series varied from 10 days to death on the same day that the last egg was deposited. This death on the last day of deposition was observed 5 times during the season. The average of the 42 cases observed was 3.1 days.

For the different series of typical *grandis* this period varied from 10 days to death on the last day of deposition. The average was 3.2 days.

For typical *thurberiæ* this period varied from 3 to 7 days with an average of 5.2 days.

For the mating of female *grandis* and male *thurberiæ* the period varied from 1 to 5 days with an average of 2.4 days.

For the mating of female *thurberiæ* and male *grandis* the period varied from 3 days to death on the last day of oviposition. The average was 1.8 days.

CESSATION OF OVIPOSITION BY HIBERNATED WEEVILS.

In connection with the discussion of early or late planting to escape the attack of the weevil it is interesting to note the time of cessation of oviposition by early hibernated weevils. The accompanying table (Table XVI) shows the date of the last egg deposited by each of the first twelve hibernated females collected in the spring. Here it is seen that the last egg ranged from May 29 to July 22.

TABLE XVI.—*Dates of cessation of oviposition of first hibernated females of the boll weevil.*

Date collected.	Date stopped ovipositing.	Date collected.	Date stopped ovipositing.
May 8	May 29	May 20	July 12
Do	June 4	Do	July 22
Do	June 19	Do	July 8
Do	June 22	Do	Do.
Do	July 10	May 10	June 14
May 20	June 14	Earliest date stopped	May 29
Do	June 15	Latest date stopped	July 22

DEPENDENCE OF REPRODUCTION UPON FOOD.

The studies of the feeding habits of the weevils in relation to malvaceous plants other than cotton and Thurberia have served to throw some further light on this subject. Many weevils were kept on cotton leaves only from emergence to death, but only one pair was observed in copula and not a single egg was found; but shortly after such females were transferred to squares or bolls they would start ovipositing more or less normally. The possibility of the shape of the square or boll being a mechanical stimulus to oviposition was considered for some time, but later in the season this idea was discarded. A female which had been fed only on the blooms of *Hibiscus syriacus* from emergence deposited a fertile egg on an open petal of a bloom. Then shortly after this several females were observed to oviposit in empty glass tubes. So it seems that oviposition is simply a question of food and fertility, although the element or elements needed for sexual maturity are not limited to cotton squares and bolls. This element is evidently not present in cotton foliage in sufficient quantities, but is present in varying amounts in cotton squares, bolls, and blooms, *Hibiscus syriacus* blooms, and also blooms of *Callirrhoë involucrata* and *C. pedata.*

DEVELOPMENT.

Only a few observations were made on the individual stages of development, although much work was done upon the whole period of development. The length of the stages was obtained by repeated examinations to learn the dates of transformation.

Incubation period.—The data on the egg stage are summarized in Table XVII.

TABLE XVII.—*Incubation period of the boll weevil.*

Date of oviposition.	Number of individuals.	Egg days.	Period.			Mean temperature.
			Minimum.	Maximum.	Average.	
Deposited normally:			*Days.*	*Days.*	*Days.*	°*F*
Aug. 23	9	18	2	2	2.0	88.5
24	8	17.6	2	3	2.2	87.6
28	20	53.8	2	3	2.69	86.8
29	17	48.28	2	4	2.84	86.1
Sept. 19	11	55.0	5	5	5.0	74.1
19	23	131.1	5	6	5.7	73.1
20	24	139.2	5	6	5.8	71.9
21	9	50.4	5	6	5.6	70.9
22	17	81.6	3.5	5.5	4.8	72.9
Total and average	138	594.9	2	6	4.3	....
Deposited externally:						
May 20	1	1	1	1	1	77.4
Aug. 20	2	4	2	2	2	86.4
Total and average	3	5	1	2	1.6	....

By this table it is noted that normally deposited eggs developed in 2 days at 88.5° and in 5.8 days at 71.9°, while eggs deposited externally and therefore directly exposed to the changes of air temperature developed in 1 day at 77.4° and in 2 days at 86.4°.

One weevil fed on flowers of *Hibiscus syriacus* deposited an egg externally on September 21. This egg hatched in 4 days at a mean temperature of 71.1°.

Larval period.—Only 26 larvæ were observed through this stage and they averaged 6 days with a minimum of 5.1 days and a maximum of 7.1 days at a mean temperature of 84.7°. One greatly retarded individual not observed to pupation required over 10 days for the period.

Pupal period.—Only 7 observations of the pupal period were made. The average period was 4.63 days, with a minimum of 4.38 days and a maximum of 5.38 days, at a mean temperature of 83.6°.

TOTAL DEVELOPMENTAL PERIOD.

The data for the total developmental period are presented in Table XVIII. Records of the development of 1,513 individuals indicate a very slightly shorter period for the females than the males. These various records are not strictly comparable until correlated with the climatic records.

TABLE XVIII.—*Data on the developmental period of the boll weevil.*

TEXAS WEEVILS.

Nature of weevils.	Larval food.	Period of oviposition.	Males.			Females.			Total number bred.	Total weevil days.	Average period.
			Number bred.	Weevil days.	Average period.	Number bred.	Weevil days.	Average period.			
					Days.			*Days.*			*Days.*
First generation	Cotton squares.	May 19-31	54	884	16.3	50	804	16.0	104	1,688	16.2
Do	...do....	June 1-5	72	1,206	16.7	75	1,249	16.6	147	2,455	16.7
Do	...do....	June 6-10	57	895	15.7	44	700	15.9	101	1,595	15.7
Do	...do....	June 11-15	48	729	15.1	33	493	14.9	81	1,222	15.0
Do	...do....	June 16-20	27	379	14.0	34	470	13.8	61	849	13.9
Do	...do....	June 21-25	36	477	13.2	40	526	13.1	76	1,003	13.1
Do	...do....	June 26-30	33	447	13.5	32	418	13.0	65	865	13.3
Do	...do....	July 1-16	12	176	14.6	13	184	14.1	25	360	14.4
Second generation	...do....	June 17-30	41	552	13.4	42	562	13.3	83	1,114	13.4
Offspring single pair.	...do....	June 25-July 12	13	178	13.7	10	134	13.4	23	312	13.5
Second generation	...do....	Aug. 19-Sept. 26	8	128	16.0	5	81	16.2	13	209	16.0
Third generation	...do....	July 7-10	3	39	13.0	5	68	13.6	8	107	13.3
Fourth generation	...do....	July 27-30	4	52	13.0	4	56	14.0	8	108	13.5
Fifth generation	...do....	Aug. 20-Sept. 9	8	133	16.6	5	72	14.4	13	205	15.7
Sixth generation	...do....	Sept. 9-17	3	56	18.6	3	57	19.0	6	113	18.8
Do	...do....	Oct. 3	....	......	......	1	21	21.0	1	21	21.0
Seventh generation	...do....	Oct. 11-14	2	43	21.5	1	21	21.0	3	64	21.3
Miscellaneous series	...do....	July 3-Aug. 2	118	1,544	13.1	91	1,170	12.8	209	2,714	13.0
True *grandis*.	...do....	May-Oct	539	7,928	14.7	488	7,086	14.5	1,027	15,014	14.6

TABLE XVIII.—*Data on the developmental period of the boll weevil*—Continued.

ARIZONA WEEVILS.

Nature of weevils.	Larval food.	Period of oviposition.	Males. Number bred.	Males. Weevil days.	Males. Average period.	Females. Number bred.	Females. Weevil days.	Females. Average period.	Total number bred.	Total weevil days.	Average period.
					Days.			*Days.*			*Days.*
First generation...	Cotton squares.	Sept. 2-24.......	20	353	17.6	12	207	17.2	32	560	17.5
Do............	...do....	May 27..........	2	38	19.0	....	......	......	2	38	19.0
Do............	...do....	Sept. 20.........	1	18	18.0	....	......	......	1	18	18.0
Do............	...do....	Sept. 3-10........	3	55	18.3	2	37	18.5	5	92	18.4
Do............	Cotton bolls.	Sept. 12-15.......	2	49	24.5	3	76	25.3	5	125	25.0
True *thurberiæ.*	Cotton forms.	May, Sept.......	28	513	18.3	17	320	18.8	45	833	18.5
Male *grandis* by female *thurberiæ:*											
First generation.	Cotton squares.	Sept. 7-Oct. 2...	11	218	19.8	13	228	17.5	24	446	18.5
Do........	...do....	June 6-July 3...	20	270	13.5	19	257	13.5	39	527	13.5
Second generation.	...do....	July 2-15.........	15	212	14.1	11	157	14.2	26	369	14.1
Total......	....	....	46	700	15.2	43	642	14.9	89	1,342	15.0
Male *thurberiæ* by female *grandis:*											
First generation.	Cotton squares.	Sept. 5-Oct. 4...	22	387	17.5	15	265	17.6	37	652	17.6
Do........	...do....	May 30-June 15..	83	1,415	17.0	73	1,049	14.3	156	2,464	15.7
Do........	...do....	June 16-30.......	35	453	12.9	39	510	13.0	74	936	13.0
Do........	...do....	July 1-7..........	17	208	12.2	18	226	12.5	35	434	12.4
Second generation.	...do....	June 24-July 6..	21	293	13.9	29	389	13.4	50	682	13.6
Total......	....	....	178	2,756	15.4	174	2,439	14.0	352	5,195	14.7
Total of all varieties.	....	1913.............	791	11,897	15.0	722	10,487	14.5	1,513	22,384	14.7

The total developmental period was also tested in the buds of *Hibiscus syriacus* during September and October. Three *thurberiæ* varied from 15 to 17 days, with an average of 16 days, and 2 *grandis* gave a period of 17 and 18 days, or an average of 17.5 days.

GENERATIONS.

In order to determine definitely the possible number of generations of weevils in one season two series were carried through the breeding season. These were to determine the maximum and minimum number of generations in cotton squares from the first hibernated females to emerge in the spring.

In the maximum series the first eggs from the first hibernated females found were saved for the emergence of the adults. The first of these adults to emerge were mated, their first eggs saved, and so on through each generation. Table XIX shows the results of this series.

TABLE XIX.—*Number of generations of the boll weevil—maximum series on squares.*

[First generation from first eggs of females that emerged from hibernation May 8 to 10.]

Generation.	Date.	Mean temperature for period.[1]	Period from maturity to maturity (about).
First generation:		°F	Days.
Eggs laid	May 19–24		
Generation mature	June 4–8	78.2	28
Second generation:			
Eggs laid	June 17–22		
Generation mature	July 1–4	80.1	26
Third generation:			
Eggs laid	July 7–10		
Generation mature	July 20–22	84.3	19
Fourth generation:			
Eggs laid	July 27–30		
Generation mature	Aug. 9–11	87.5	20
Fifth generation:			
Eggs laid	Aug. 19–22		
Generation mature	Sept. 3–5	85.2	25
Sixth generation:			
Eggs laid	Sept. 8–10		
Generation mature	Sept. 27–29	76.5	24
Seventh generation:			
Eggs laid	Oct. 7–11		
Generation mature	Nov. 2–4	69.8	36

[1] The period referred to here is that from the average time of emergence of a generation to the same time in the next generation.

The weevils were very unusually late in emerging from hibernation at Victoria in the spring of 1913, the first being found on May 8. This is at least two or three weeks later than the usual time. As a result, nearly one complete generation was cut off the first of the season. The last generation secured in the breeding series was the seventh. The adults of this generation emerged November 2 to 4. At this time the cool weather had practically stopped all breeding in both cages and field, and this was considered to be the last generation. However, the weather became warmer in the latter part of November and December, and on the 26th of December Mr. J. D. Mitchell found breeding in progress in the field. This was evidently a case of an extra generation caused by the unusually warm weather after the starting of hibernation. The maximum number of generations in squares at Victoria in a normal season is evidently seven or eight.

The minimum generation series was conducted quite differently. The last eggs were secured from the hibernated females used in starting the maximum series. The last adults reared from these eggs were mated and their last eggs secured. The results of this series are shown in Table XX. The last adults of the second generation did not mature until October 13 to 15, and as these certainly would enter hibernation this was considered as the minimum number of generations from the first hibernated females. As the last females to emerge from hibernation in the spring would continue ovipositing much longer and the last weevils of the first reared generation would mature much later in the season, it seems quite possible for weevils of the first generation to enter hibernation in the fall.

TABLE XX.—*Number of generations of the boll weevil—minimum series on squares.*

[First generation from last eggs of females that emerged from hibernation May 8 to 10.]

Generation.	Date.	Period from maturity to maturity (about).	Mean temperature for period.
First generation:		*Days.*	°*F.*
Last eggs laid	July 14–16		
Generation mature	July 29–30	81	80.7
Last generation:			
Last eggs laid	Sept. 26–30		
Generation mature	Oct. 13–15	78	80.7

HIBERNATION.

The hibernation of variety *thurberiæ* in bolls of Thurberia is longer than any other phase of this phenomenon for the species. The adults mature in their cells before December, but remain therein until August or later around Tucson, Ariz. When removed from the cells they begin activity immediately.

NATURAL CONTROL.

Parasitism.—The parasitism of native weevil stages at Victoria during the season was very slight. In spite of the large numbers of infested squares and bolls collected in the field and held for the emergence of weevils, not a single parasite was reared. Several hundred infested squares and bolls were opened during the season and only one parasite larva was found.

Late in the season two lots of squares were sent to the writer from Tallulah, La., by Mr. G. D. Smith. These were placed in cages for the emergence of adults and five species of parasites emerged. These were: *Bracon mellitor* Say; *Catolaccus incertus* Ashm.; *Catolaccus hunteri* Cwfd.; *Cerambycobius cyaniceps* Ashm.; *Eurytoma tylodermatis* Ashm. Of these Bracon was much the more abundant.

From the *thurberiæ* imported from Arizona only one parasite was reared at Victoria. This was a specimen of *Eurytoma* sp. which had parasitized a weevil larva.

During September what threatened to be a serious outbreak of a mite (probably *Pediculoides* sp.) appeared in the various breeding series. This infestation spread rapidly over many of the shelves where immature stages of weevils were being reared and soon killed a considerable number of these. This infestation was evidently controlled by the cool weather and no further trouble was experienced.

Messrs. Schwarz and Barber found in Thurberia bolls two individuals parasitized by Ichneumonoidea.

Disease.—During the latter part of the season a curious epidemic of deaths of newly emerged weevils occurred in one breeding series.

Little attention was paid to the deaths at first, but in about three days nearly all weevils in this series had died. It was then noted that instead of presenting the usual appearance of death the weevils became very dark in color, almost black, in fact. On touching these weevils it was found that they were very soft and the body contents were liquified. This liquid had the usual dark color and characteristic odor of flacherie of lepidopterous larvæ. The source of the seemingly diseased weevils was investigated, and it was found that all came from squares kept in a California breeding box which had contained lepidopterous larvæ infected with flacherie only a short time previously. Two of the dead weevils were submitted to Dr. G. F. White, of this bureau, for bacteriological examination, and he reported as follows:

> In the examinations made the findings in the two specimens are the same. The direct examination shows the presence of a very large number of microorganisms, which seem to be bacteria. The appearances suggest that most of these organisms belong to one species. Comparatively few colonies appeared in plate cultures made from the material. There is some indication, therefore, that the trouble is bacterial in origin. These results can be interpreted, of course, only as suggesting the possibility.

While the results secured by Dr. White are by no means conclusive, they do, as he says, suggest the possibility of a bacterial disease of the boll weevil. Although it is but a mere possibility, there is evidently an opportunity for considerable profitable investigation of the subject.

BEHAVIOR OF LOUISIANA WEEVILS AT VICTORIA.

Late in the season a number of infested squares were imported from Tallulah, La., in order to test the weevils emerging from them in their various life functions in comparison with Texas weevils. As the work was interrupted by the cool weather very little was learned from the series, but some results of interest were secured. Four pairs of weevils were mated on cotton squares immediately after emergence and tested for fecundity. These weevils emerged on September 18 and on September 20 one female deposited 1 egg and another deposited 2. The latter female deposited another egg on September 22, and then neither of these two deposited any more eggs before the series was closed on October 29. The third female lived through the same period and did not deposit an egg. The fourth female emerged September 20, deposited 1 egg on September 22, and then waited 14 days before depositing another. Then deposition started normally and 37 eggs were laid in the next 23 days. These results are very peculiar, especially the fact that three out of the four females began deposition on the second day after emergence and then stopped; two of them permanently and one for a period of 14 days.

The eggs deposited were tested for the maturing of adults, but none emerged, possibly owing to the cold weather. Native weevils were maturing in small numbers under the same conditions at this time, but as the number tested was so small there may not be any significance in this fact.

These weevils were also tested for their ability to subsist on a diet of *Hibiscus syriacus*. The detailed results of this test have been published in the paper on the feeding habits of the weevils. As only blooms were available no tests were made of the ability of these weevils to breed in the buds of this plant, but they seemed as well adapted to the plant as the native and Thurberia weevils.

DEVELOPMENT OF THURBERIA THESPESIOIDES.

On May 21 a supply of seeds of Thurberia from the Santa Rita Mountains, Ariz., were planted at Victoria. A bed of rather sandy soil was selected in a well-drained situation. On May 26 the first seedling appeared above the ground and 11 plants were visible by June 1. Although over 100 seeds were planted only these 11 sprouted.

These plants grew rather rapidly for a couple of months but formed no lateral branches of any consequence. The growth was entirely upward and the stems were very thin, causing the plants to require staking to prevent drooping. About August 20 a number of fruiting branches appeared near the top of the plants and these developed very rapidly. At this time the larger plants were 3½ feet in height. On August 26 the first bud was observed and many more appeared daily for a period of about three weeks. Then fruiting was discontinued for a couple of weeks followed by the production of more fruiting branches. These plants continued to grow with intermittent formation of buds until the observations were discontinued on November 6. At this time several of the plants were more than 4 feet in height.

At Batesburg, S. C., Mr. E. A. McGregor planted about 100 of these seeds in a sandy bed. Not a single one of these appeared above the soil.

At Tallulah, La., Mr. G. D. Smith planted a number of seeds and only one sprouted. This plant lived through the season.

EXAMINATION OF THURBERIA BOLLS.

On March 10, 1914, the writer examined part of a lot of infested Thurberia bolls which had been collected by Messrs. Schwarz and Barber at from 4,500 to 5,000 feet altitude in Stone Cabin Canyon, Santa Rita Mountains, Ariz., on December 6, 1913. These bolls were shipped to Washington shortly after collection and placed in a cool cellar there until the day of examination. Seventy-seven of

the bolls yielded a total of 84 live weevils; one containing 3, 5 others containing 2 each, and the remainder containing 1 each. One boll had been completely eaten out by a bollworm, and another showed signs of weevil injury and a braconid parasite cocoon. Two dead pupæ and 2 dead larvæ were found in 4 other bolls. Their deaths were in all probability due to climatic causes. The remaining boll contained signs of weevil larval work, but no insects, either dead or alive, were found. One boll which contained a weevil adult also contained a tiny, light-green lepidopterous larva.

Of the 84 weevils found in the bolls, 52 were males and 32 were females. One additional male was found crawling among the bolls when the bag was opened. Those in the bolls were all tightly sealed in the pupal cells and were usually quiet when first opened. As soon as the weevils were exposed to the air they became quite active and remained that way.

The peculiar feeding habit of the larvæ of these weevils is certainly well adapted to destroying the maximum number of seeds in a boll. They do practically all their feeding in the center of the boll and form the pupal cells in this same place. Owing to the arrangement of the seeds this location of the larva enables it to injure practically every seed in the boll instead of injuring those of one lock as is usual with the cotton weevils.

On March 12, 1914, another lot of infested Thurberia bolls were examined. These were collected by Mr. Schwarz in a small canyon between Stone Cabin and Sawmill Canyons, Santa Rita Mountains, Ariz., on December 7, 1913, at about 3,900 feet altitude. The bolls were sent to Washington soon after collection and had been in a cool cellar from that time until examined.

Examination of 39 of the bolls showed 2 clean and the remainder infested. Thirty-three bolls yielded 36 live weevils, 3 bolls containing 2 each. Three dead adults (2 females and 1 male) were found in as many bolls. These deaths were probably due to climatic causes. One boll was found which showed signs of larval injury but the larva was not to be found. No signs of parasitism were found. One lepidopterous larva like the one noted in the preceding lot was found in a boll with a weevil. The live weevils consisted of 18 males and 18 females.

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 232

Contribution from the Forest Service, Henry S. Graves, Forester, in cooperation with the Bureau of Crop Estimates, Leon M. Estabrook, Chief.
June 26, 1915.

(PROFESSIONAL PAPER.)

THE PRODUCTION OF LUMBER IN 1913.

By the Office of Industrial Investigations.

CONTENTS.

INTRODUCTION.

This bulletin presents statistics showing the production of lumber in the United States in 1913. A preliminary report issued in 1914 gave the basic information obtained in this census and it is the purpose of this publication to complete the record through a much more detailed presentation of the figures.

For several years previous to 1913 lumber production statistics were collected by the Bureau of the Census in cooperation with the Forest Service, but the figures for 1913 were collected by the Bureau of Crop Estimates of the Department of Agriculture in cooperation with the Forest Service. The work will be resumed by the Bureau of the Census for 1914.

It was necessary to rely chiefly upon correspondence in securing reports from the mills. As in former years, the New York statistics were furnished by the Conservation Commission of that State.

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Attention is called to the fact that the statistics for different years are not exactly comparable on account of the varying number of small mills which made returns in the different years. In 1899 and 1909 the enumeration was exceptionally complete, special agents of the Bureau of the Census canvassing the mills in connection with the decennial census of manufacturers. Further, mills reporting less than 50,000 feet of lumber were omitted from the statistics for 1910 and later, and the census of 1904 was limited to merchant mills, thus excluding probably a somewhat larger proportion, while for the other years previous to 1910, except 1904, all mills for which reports were secured are included in the statistics. The figures for 1907, 1908, 1910, 1911, and 1912 were secured by correspondence methods which make the figures for those years more nearly comparable.

The census for 1913 is characterized by the grouping of mills into capacity classes and concentrating efforts upon an attempt to secure as complete a census as possible by correspondence from the mills in the larger classes, without attempting to follow up reports from thousands of small mills. It is believed that if the figures are separated in this manner in this and succeeding presentations of annual lumber statistics a ready means of comparison of the production of the mills in different years will be afforded, even though the number of small mills reporting may vary considerably.

Table 1 shows the lumber cut for each year since 1899 from which data have been compiled and the number of active mills reporting each year.

TABLE 1.—*Number of active mills reporting and quantity of lumber, 1899–1913.*

Year.	Number of active mills reporting.	Lumber (quantity, M feet b. m.).	Year.	Number of active mills reporting.	Lumber (quantity, M feet b. m.).
1913	[1] 21,668	38,387,009	1908	31,231	33,224,369
1912	29,648	39,158,414	1907	28,850	40,256,154
1911	28,107	37,003,207	1906	22,393	37,550,736
1910	31,934	40,018,282	1904	18,277	34,135,139
1909	48,112	44,509,761	1899	31,833	35,084,166

[1] In 1913 the number of active mills includes only those cutting lumber, while the figures for the other years include mills cutting lath and shingles as well as lumber.

In 1913, 21,394 mills reported a production of 38,387,009,000 board feet, as against 39,158,414,000 feet reported by 29,648 mills in 1912, and 37,003,207,000 feet reported by 28,107 mills in 1911. Although about 8,000 fewer mills reported in 1913 than in 1912 many were exclusively shingle mills, while most of the lumber mills not reporting were of small capacity and the inclusion of their reports would not change the total production in the same ratio.

The production in 1913 of nearly as much lumber as in 1912 is of special significance in view of the business conditions which have

existed in the industry. During the first three months of the year the lumber trade was much improved, but in the second quarter the demand for lumber fell off noticeably. Further weakening in the demand during the summer led to decreased production in the yellow-pine and Douglas-fir regions for short periods. The fall demand did not improve. In general the year was one of overproduction and slack business in the principal lumber manufacturing regions.

Notwithstanding temporary decreases in the production of yellow pine and Douglas fir, the reported cut of yellow pine was about seven-tenths of 1 per cent and of Douglas fir about 7½ per cent greater in 1913 than in 1912. The cut of Douglas fir in 1913 was the largest ever reported, while the 1913 cut of yellow pine was second only to that of 1909. Had not enforced curtailment in the output of these two woods been necessary, the total lumber production of 1913 would undoubtedly have exceeded that of 1912. In fact, had not the cut of white pine, hemlock, spruce, oak, and maple declined in 1913, the increased cut of yellow pine, Douglas fir, cypress, and red gum in that year would have carried the total lumber production beyond that for 1912.

The increased cut of certain woods is reflected in the increased production of Washington, Oregon, and the lower Mississippi Valley States, while the decreased cut of other woods is reflected in the decreased production of the Northern, Central, and Atlantic States. The reported production of 4,592,055,000 feet in Washington in 1913 was the largest ever recorded for that State or any other State. The largest production previously reported by one State was that of 4,311,240,000 feet in 1890, by Michigan.

Of the total reported production of lumber, softwoods contributed 30,302,549,000 feet board measure in 1913, as against 30,526,416,000 feet in 1912, and 28,902,388,000 feet in 1911.

Table 2 shows the total production of lumber in 1913 by production classes of sawmills. It will be noted that mills having an annual production of less than 50,000 feet are not considered in this report. If reports from such mills had been included the total production would probably not have been increased by more than one-half of 1 per cent, since in 1909 when the production of such mills was included it was found that although there were 4,543 such mills they cut but three-tenths of 1 per cent of the total lumber produced. Table 2 shows the importance of the large sawmill in furnishing the country's supply of lumber, and it also shows how practically correct figures on lumber production can be secured by getting reports from mills of the largest two or three classes only.

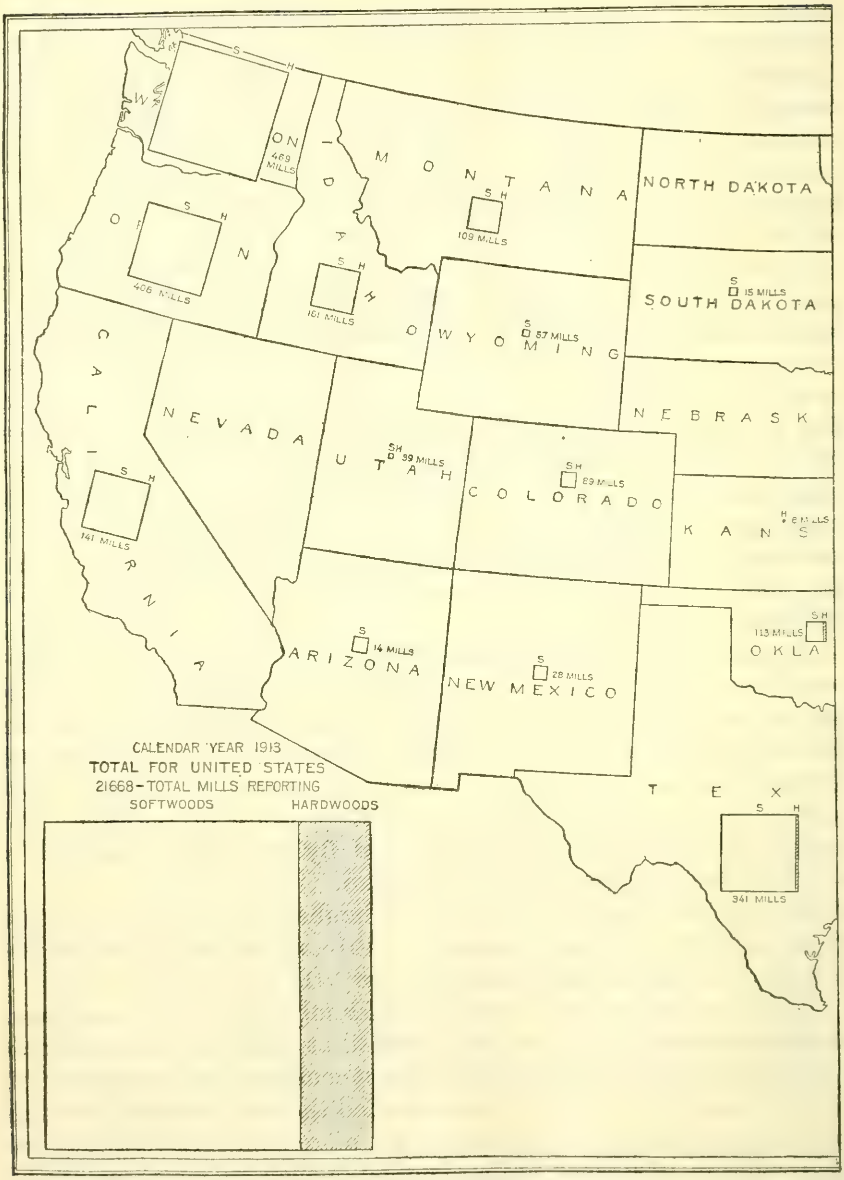

FIG. 1.—Production of the different kinds of lumber, by States, for the calendar year 1913.

[The squares printed on the map represent the total production of lumber in the several States; the two parts of the squares separated by the vertical dividing lines represent the production of softwood (S) and hardwood (H), respectively.]

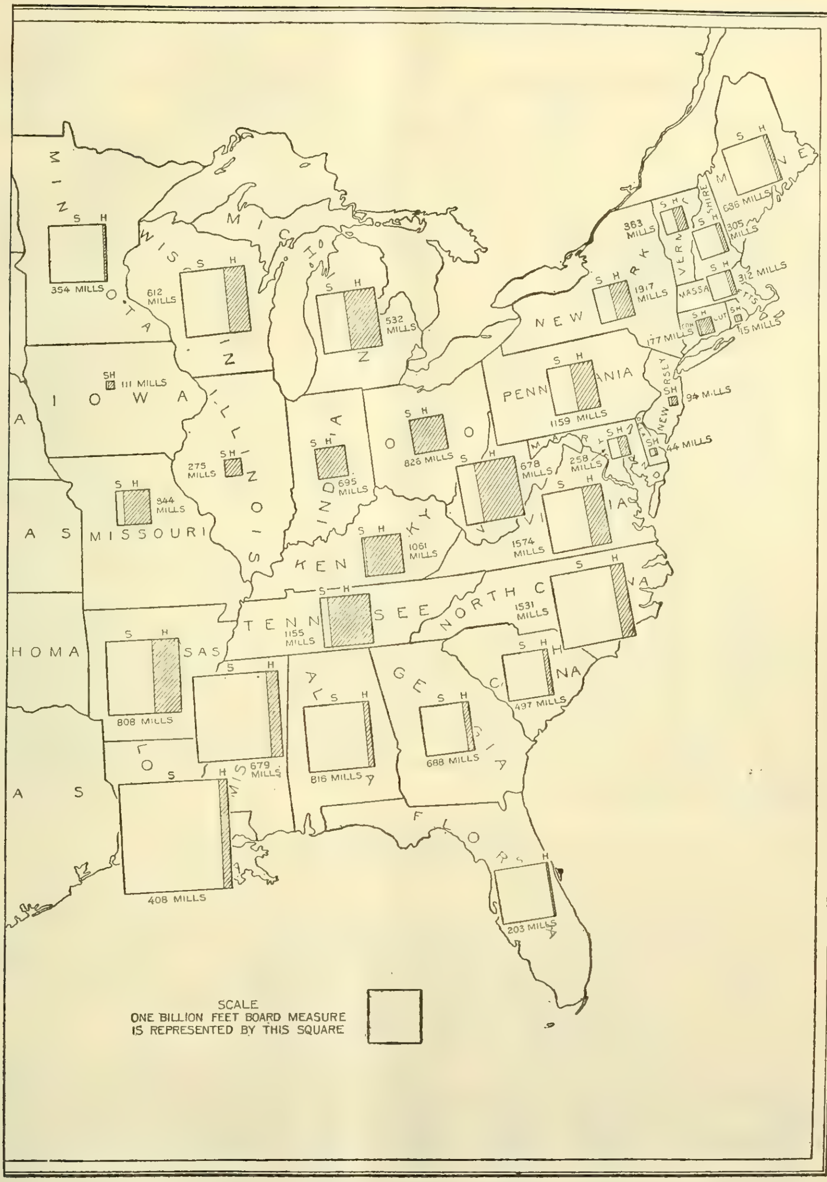

FIG. 1a.—Production of the different kinds of lumber, by States, for the calendar year 1913.

[The squares printed on the map represent the total production of lumber in the several States; the two parts of the squares separated by the vertical dividing lines represent the production of softwood (S) and hardwood (H), respectively.]

TABLE 2.—*Total production of lumber in 1913 by production classes of sawmills.*

Production group classes.	Number of mills reporting.	Per cent of total number of mills reporting.	Reported cut.	Per cent of total reported cut.
			Thousand board feet.	
United States	21,668	100.0	38,387,009	100.0
Class 5—10,000 M board feet and over	974	4.5	23,211,667	60.5
Class 4—5,000 M to 10,000 M board feet	740	3.4	4,303,122	11.2
Class 3—1,000 M to 5,000 M board feet	3,265	15.1	6,319,753	16.5
Class 2—500 M to 1,000 M board feet	3,148	14.5	2,049,642	5.3
Class 1—50 M to 500 M board feet	13,541	62.5	2,502,825	6.5

Table 3 shows the production by capacity classes, as does Table 2, but here the amounts are listed by kinds of woods. This table shows that the quantity of each kind of lumber sawed by the different capacity classes of sawmills indicates that about 60 per cent of the total lumber production in 1913 was sawed by mills cutting 10,000,000 feet and over annually. Some of these mills cut but one kind of wood, such as yellow pine or Douglas fir, but others cut several kinds, as in the case of hemlock and hardwood mills in the Lake States. The table, therefore, should not be interpreted to indicate the existence of mills of any class sawing any wood exclusively. Mills sawing 10,000,000 feet and over annually sawed in 1909, the only other year for which such figures are available, 19,125,123,000 feet, or 43 per cent of the total quantity of lumber cut in that year, while mills of the other classes produced somewhat larger proportions of the total lumber cut than in 1913.

TABLE 3.—*Lumber sawed.*

(M feet b. m.)

Kind of wood.	1913						Total 1912.	Total 1911.
	Mills sawing 10,000 M and over annually—Group 5.	Mills sawing 5,000 M to 10,000 M annually—Group 4.	Mills sawing 1,000 M to 5,000 M annually—Group 3.	Mills sawing 500 M to 1,000 M annually—Group 2.	Mills sawing 50 M to 500 M annually—Group 1.	Total.		
1. Yellow pine	9,256,536	1,732,716	2,657,104	676,368	516,639	14,839,363	14,737,052	12,896,706
2. Douglas fir	4,771,302	408,387	286,631	42,959	46,817	5,556,096	5,175,123	5,054,243
3. Oak	557,414	486,152	906,194	494,951	767,007	3,211,718	3,318,952	3,098,444
4. White pine	1,659,990	147,732	442,551	140,317	178,046	2,568,636	3,138,227	3,230,584
5. Hemlock	1,573,094	245,454	265,776	80,595	155,063	2,319,982	2,426,554	2,555,308
6. Western pine	855,385	127,964	166,701	43,741	64,737	1,258,528	1,219,444	1,330,700
7 Cypress	864,700	108,420	101,494	14,325	8,308	1,097,247	997,227	981,527
8. Spruce	643,752	132,716	166,243	54,042	50,063	1,046,816	1,238,600	1,261,728
9. Maple	429,317	99,198	181,068	77,033	111,871	901,487	1,020,864	951,667
10. Red gum	277,591	195,056	205,059	43,480	51,328	772,514	694,260	582,967
11. Yellow poplar	185,252	119,647	169,211	66,862	79,204	620,176	623,289	659,175
12. Redwood	476,527	26,485	4,250	1,550	1,459	510,271	496,796	489,768
13. Chestnut	118,791	76,491	142,563	79,603	88,354	505,802	554,230	529,022
14. Larch	301,796	46,369	27,594	6,795	12,719	395,273	407,064	368,216
15. Birch	170,376	49,954	91,736	29,757	36,916	378,739	388,272	432,571
16. Beech	94,641	29,411	93,866	56,990	90,593	365,501	435,250	403,881
17. Cedar	277,087	36,341	30,056	7,546	7,414	358,444	329,000	374,925
18. Basswood	107,515	35,833	42,777	23,385	47,592	257,102	296,717	304,621
19. Elm	70,369	22,193	44,222	21,974	55,774	214,532	262,141	236,108
20. Cottonwood	88,289	56,459	38,632	7,522	18,036	208,938	227,477	198,629
21. Ash	52,146	39,695	63,586	22,010	30,379	207,816	234,548	214,398
22. Hickory	14,726	12,325	72,047	27,438	36,444	162,980	278,757	240,217

TABLE 3.—*Lumber sawed*—Continued.

Kind of wood.	1913						Total 1912.	Total 1911.
	Mills sawing 10,000 M and over annually—Group 5.	Mills sawing 5,000 M to 10,000 M annually—Group 4.	Mills sawing 1,000 M to 5,000 M annually—Group 3.	Mills sawing 500 M to 1,000 M annually—Group 2.	Mills sawing 50 M to 500 M annually—Group 1.	Total.		
23. Sugar pine	134,396	4,175	10,233	632	490	149,926	132,416	117,987
24. Tupelo	67,891	27,959	19,977	3,108	1,485	120,420	122,545	98,142
25. Balsam fir	34,241	7,438	24,889	13,233	13,951	93,752	84,261	83,375
26. White fir	75,346	4,683	5,020	1,255	1,805	88,109	122,613	124,307
27. Walnut	4,668	5,860	19,924	4,463	5,650	40,565	43,083	38,293
28. Mahogany	22,750	8,004	4,410	615	482	36,261	29,209	21,328
29. Sycamore	11,659	2,727	5,207	2,767	8,444	30,804	49,468	42,836
30. Lodgepole pine			12,925	1,020	6,161	20,106	22,039	33,014
31. Cherry	5,205	802	3,839	1,421	2,859	14,126	22,245	21,422
32. Buckeye	2,323	948	1,804	347	1,000	6,422	13,742	11,737
33. Locust	122	206	3,775	13	391	5,507	5,058	5,450
34. Willow	3,462	790	200	42	259	4,753	2,961	1,130
35. Cucumber	860	1,168	424	347	625	3,424	1,031	
36. Magnolia	40	1,605	1,297	220	106	3,268	122	2,418
37. Hackberry	510	399	277	260	669	2,115	157	
38. Butternut	640	239	504	244	337	1,964	633	
39. Persimmon	10		1,125	175	594	1,904	1,577	
40. Dogwood			1,000	50	323	1,373	2,584	
41. Pecan		75	367	162	486	1,090		
42. Ebony		1,000				1,000		
43. Spanish cedar	750					750		
44. Alder			20		505	525		
45. Apple					269	269	178	
46. Silverbell	194					194	395	
47. Jenisero			100		33	133	150	
48. Sassafras	4	45	50	15	12	126	16	
49. Eucalyptus					50	50	75	
50. Hornbeam					35	35		
51. Bois d'Arc			25		10	35	311	1,210
52. Madrona					25	25		
53. Coffeetree				5		5		
54. Mulberry		1		4		5	1	
55. Crabapple					4	4		
56. Ironwood				1	1	2		
57. Chinquapin					1	1		
Minor species, 1912 and 1911							1,700	4,853
Total	23,211,667	4,303,122	6,319,753	2,049,642	2,502,825	38,387,009	39,158,414	37,003,207

Table 4 shows the lumber production by States for the years 1913, 1912, and 1911, and also shows the number of active mills reporting in each year.

TABLE 4.—*Number of active lumber mills reporting and quantity of lumber sawed, by States, 1913, 1912, and 1911.*

State.	Number of active mills reporting.			Lumber sawed (M feet b. m.).			Number of mills reporting idle, 1913.
	1913	1912	1911	1913	1912	1911	
United States	21,668	29,648	28,107	38,387,009	39,158,414	37,003,207	4,674
Washington	469	788	777	4,592,053	4,099,775	4,064,754	51
Louisiana	408	460	502	4,161,560	3,876,211	3,566,456	75
Mississippi	679	952	908	2,610,581	2,381,898	2,041,615	162
Oregon	406	480	522	2,098,467	1,916,160	1,803,698	125
Texas	341	450	430	2,081,471	1,902,201	1,681,080	79
North Carolina	1,531	2,418	2,071	1,957,258	2,193,308	1,798,724	395
Arkansas	808	1,145	1,127	1,911,647	1,821,811	1,777,303	168
Alabama	816	1,249	1,112	1,523,936	1,378,151	1,226,212	214
Wisconsin	612	792	771	1,493,353	1,498,876	1,761,986	137
Virginia	1,574	2,126	2,005	1,273,953	1,569,997	1,359,790	348
West Virginia	678	961	994	1,249,559	1,318,732	1,387,786	153
Michigan	532	792	796	1,222,983	1,488,827	1,466,754	96
California	141	229	222	1,183,380	1,203,059	1,207,561	84
Minnesota	354	484	467	1,149,704	1,436,726	1,485,015	87
Florida	203	397	295	1,055,047	1,067,525	983,824	64

TABLE 4.—*Number of active lumber mills reporting and quantity of lumber sawed, by States, 1913, 1912, and 1911*—Continued.

State.	Number of active mills reporting.			Lumber sawed (M feet b. m.).			Number of mills reporting idle, 1913.
	1913	1912	1911	1913	1912	1911	
Tennessee	1,155	1,567	1,536	872,311	932,572	914,579	225
Georgia	688	1,117	952	844,284	941,291	801,611	209
Maine	686	826	817	834,673	882,128	828,417	76
Pennsylvania	1,159	1,724	1,636	781,547	992,180	1,048,606	371
South Carolina	497	750	541	752,184	816,930	584,872	120
Idaho	161	202	209	652,616	713,575	765,670	57
Kentucky	1,061	1,386	1,452	541,531	641,296	632,415	249
New York	1,917	1,487	1,520	457,720	502,351	526,283	....
Missouri	844	1,210	1,112	416,608	422,470	418,586	204
Ohio	826	1,156	1,009	414,943	499,834	427,161	151
Montana	109	118	126	357,974	272,174	228,416	33
Indiana	695	978	915	332,993	401,017	360,613	145
New Hampshire	305	441	397	309,424	479,499	388,619	64
Massachusetts	312	420	430	224,580	259,329	273,317	85
Vermont	363	507	498	194,647	235,983	239,254	63
Maryland	258	404	389	140,469	174,320	144,078	10
Oklahoma	113	200	174	140,284	168,806	143,869	28
Illinois	275	463	394	102,902	122,528	96,651	96
Connecticut	177	215	218	93,730	109,251	124,661	42
Arizona	14	12	12	77,363	76,287	73,139	0
Colorado	89	135	156	74,602	88,451	95,908	75
New Mexico	28	41	47	65,818	82,650	83,728	12
New Jersey	94	146	136	27,248	34,810	28,639	23
Iowa	111	157	160	21,676	46,593	59,974	28
South Dakota	15	28	28	19,103	20,986	13,046	11
Delaware	44	86	82	18,039	28,285	23,853	15
Rhode Island	15	22	20	14,984	14,421	9,016	4
Wyoming	57	56	75	12,940	13,560	33,309	17
Utah	39	59	62	5,403	9,055	10,573	20
All other States [1]	9	12	5	19,461	22,525	11,786	3

[1] Includes Kansas, Nebraska, and Nevada.

Table 5 shows the lumber production by kinds of wood for the years 1913, 1912, and 1911, and also the per cent of increase and the per cent of distribution for each year.

TABLE 5.—*Quantity of lumber sawed, with per cent of increase and per cent of distribution, by kinds of wood, 1913, 1912, and 1911.*

Kind of wood.	Quantity (M feet b. m.).			Per cent of increase.[1]		Per cent of distribution.		
	1913	1912	1911	1912 to 1913	1911 to 1912	1913	1912	1911
Total	38,387,009	39,158,414	37,003,207	− 2.0	5.8	100.0	100.0	100.0
Yellow pine	14,839,363	14,737,052	12,896,706	.7	14.3	38.7	37.6	34.9
Douglas fir	5,556,096	5,175,123	5,054,243	7.4	2.4	14.5	13.2	13.7
Oak	3,211,718	3,318,952	3,098,444	− 3.2	7.1	8.4	8.5	8.4
White pine	2,568,636	3,138,227	3,230,584	−18.2	− 2.9	6.7	8.0	8.7
Hemlock	2,319,982	2,426,554	2,555,308	− 4.4	− 5.0	6.0	6.2	6.9
Western pine	1,258,528	1,219,444	1,330,700	3.2	− 8.4	3.3	3.1	3.6
Cypress	1,097,247	997,227	981,527	10.0	1.6	2.9	2.5	2.7
Spruce	1,046,816	1,238,600	1,261,728	−15.5	− 1.8	2.7	3.2	3.4
Maple	901,487	1,020,864	951,667	−11.7	7.3	2.4	2.6	2.6
Red gum	772,514	694,260	582,967	11.3	19.1	2.0	1.8	1.6
Yellow poplar	620,176	623,289	659,475	− .5	− 5.5	1.6	1.6	1.8
Redwood	510,271	496,796	489,768	2.7	1.4	1.3	1.3	1.3
Chestnut	505,802	554,230	529,022	− 8.7	4.8	1.3	1.4	1.4
Larch	395,273	407,064	368,216	− 2.9	10.6	1.0	1.0	1.0
Birch	378,739	388,272	432,571	− 2.5	−10.2	1.0	1.0	1.2
Beech	365,501	435,250	403,881	−16.0	7.8	1.0	1.1	1.1
Cedar	358,444	329,000	374,925	8.9	−12.2	.9	.8	1.0
Basswood	257,102	296,717	304,621	−13.4	− 2.6	.7	.8	.8
Elm	214,532	262,141	236,108	−18.2	11.0	.6	.7	.6
Cottonwood	208,938	227,477	198,629	− 8.1	14.5	.5	.6	.5
Ash	207,816	231,548	214,398	−11.4	9.4	.5	.6	.6
Hickory	162,980	278,757	240,217	−41.5	16.0	.4	.7	.6

[1] A minus sign (−) denotes decrease.

TABLE 5.—*Quantity of lumber sawed, with per cent of increase and per cent of distribution, by kinds of wood, 1913, 1912, and 1911*—Continued.

Kind of wood.	Quantity (M feet b. m.).			Per cent of increase.		Per cent of distribution.		
	1913	1912	1911	1912 to 1913	1911 to 1912	1913	1912	1911
Sugar pine	149,926	132,416	117,987	13.2	12.2	0.4	0.3	0.3
Tupelo	120,420	122,545	98,142	− 1.7	24.9	.3	.3	.3
Balsam fir	93,752	84,261	83,375	11.3	1.1	.2	.2	.2
White fir	88,109	122,613	124,307	−28.1	− 1.4	.2	.3	.3
Walnut	40,565	43,083	38,293	− 5.8	12.5	.1	.1	.1
Sycamore	30,804	49,468	42,836	−37.7	15.5	.1	.1	.1
Lodgepole pine	20,106	22,039	33,014	− 8.8	−33.2	.1	.1	.1
Minor species[1]	85,366	82,145	69,548	3.9	18.1	.2	.2	.2

[1] See Table 34 for kinds of wood included and quantities of the more important kinds.

YELLOW PINE.

Yellow-pine lumber is cut from a number of species growing east of the Rocky Mountains. Three of them furnish most of the material, although the minor species are cut to a limited extent. There is a growing tendency to purchase southern yellow pine under specifications which designate the quality of the wood desired for the purpose, irrespective of species, to avoid the present confusion at lumber inspection points. The several species with their ranges follow:

Longleaf pine (*Pinus palustris*) occurs on the coastal plains from extreme southeast Virginia to Texas, and in the whole Florida peninsula except the extreme southern part.

Shortleaf pine (*Pinus echinata*) has its range north of that of longleaf, as far as New York, but likewise extending from the Atlantic coast to Texas and Oklahoma, and running northward to southern Missouri, West Virginia, and New Jersey.

Loblolly pine (*Pinus tæda*) grows in approximately the same region as longleaf, as far north as New Jersey, but not in as large solid bodies and it is found farther north and west than longleaf pine. This and the two preceding species furnish the bulk of yellow-pine lumber.

Slash pine (*Pinus heterophylla*), sometimes called Cuban pine, ranges throughout Florida, northward to South Carolina, and westward to Mississippi.

Spruce pine (*Pinus glabra*) ranges through southern South Carolina, the southern portions of Georgia, Alabama, and Mississippi, southeastern Louisiana and northwestern Florida.

Pond pine (*Pinus serotina*) is found along the coast and a hundred miles or so inland from southern Virginia to western Florida, but not in the southern half of the Florida peninsula.

Sand pine (*Pinus clausa*) is confined almost wholly to Florida and southern Alabama.

Scrub pine (*Pinus virginiana*) occurs from northern New Jersey to southern Indiana and southward to central Georgia.

Pitch pine (*Pinus rigida*) occurs from Georgia to New Brunswick and westward to Tennessee and Ohio.

Table Mountain pine (*Pinus pungens*) grows among the Appalachian ranges from northeastern Pennsylvania to northern Georgia.

Longleaf pine is milled mostly in the Gulf States, including Georgia and Florida. The yellow pine produced by mills in Arkansas and the lumber known commercially as North Carolina pine and coming from Virginia, North Carolina, and South Carolina include both loblolly pine and shortleaf pine. Slash pine (*Pinus heterophylla*), a wood of many excellent qualities, is cut to some extent in Florida and other southeastern States and is usually sold along with longleaf pine.

There are a number of yellow pines in the West which are not in the same commercial group as those of the East and South. One of them, called western yellow pine (*Pinus ponderosa*) is specially reported in Table 11; the others are at present of little importance in the lumber output.

Table 6 shows the production of yellow pine by States in the year 1913 and also the number of active mills in each State.

TABLE 6.—*Yellow-pine lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	7,639	14,839,363	100.0
Louisiana	299	3,092,375	20.8
Mississippi	540	2,224,711	15.0
Texas	317	2,024,231	13.7
North Carolina	1,522	1,515,102	10.2
Alabama	744	1,395,059	9.4
Arkansas	467	1,174,498	7.9
Florida	193	923,873	6.2
Virginia	1,023	810,362	5.5
Georgia	671	662,043	4.5
South Carolina	492	635,426	4.3
Oklahoma	55	120,860	.8
Maryland	165	65,143	.4
Tennessee	343	60,137	.4
Missouri	130	57,023	.4
All other States [1]	678	78,520	.5

[1] Includes establishments distributed as follows: Connecticut, 24; Delaware, 35; Illinois, 3; Indiana, 2; Iowa, 2; Kentucky, 195; Maine, 25; Massachusetts, 30; New Hampshire, 3; New Jersey, 46; Ohio, 25; Pennsylvania, 193; Rhode Island, 6; Vermont, 3; and West Virginia, 86.

DOUGLAS FIR.

Douglas fir (*Pseudotsuga taxifolia*) yields more lumber annually than any other single species of the United States. The best stands of timber are found in the northwestern coast States but Douglas fir is also cut to some extent in the Rocky Mountain region.

TABLE 7.—*Douglas fir lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	980	5,556,096	100.0
Washington	393	3,615,430	65.1
Oregon	319	1,675,391	30.2
California	69	132,176	2.4
Idaho	108	67,112	1.2
Montana	68	63,494	1.1
All other States [1]	23	2,493	0.0

[1] Includes establishments distributed as follows: Arizona, 2; Colorado, 7; New Mexico, 2; Utah, 4; and Wyoming, 8.

OAK.

While the sawmill statistics group all oak timber as if it were cut from a single species, there are, in fact, 50 or more kinds of oak in the United States, divided nearly equally between white and red oaks, the two classes generally recognized commercially. The bulk of oak lumber is cut from less than a dozen species. The wood of the red oaks is usually tinged with red, hence the name. The largest part of the country's oak lumber is furnished by the following trees:

White oak (*Quercus alba*) is the common tree of the name in the eastern half of the United States. It is as widely dispersed as any other.

Post oak (*Quercus minor*) has practically the same range as common white oak but is less abundant.

Bur oak (*Quercus macrocarpa*) occurs from the northern Atlantic coast to the eastern base of the Rocky Mountains in Montana, and southward to Tennessee and Texas.

Overcup or forked-leaf white oak (*Quercus lyrata*) is the most important of the southern white oaks. Its best development is in the lower Mississippi Valley.

Cow or basket oak (*Quercus michauxii*) is confined principally to the States south of the Ohio and Potomac Rivers.

Chestnut oak (*Quercus prinus*) ranges through the northeastern States, extending a hundred miles or more westward of the Appalachian Mountains and southward to Alabama.

The foregoing are white oaks, and are so classed in the forest and at the mill yard. The six species which follow are red oaks:

The common red oak (*Quercus rubra*) is a northern tree ranging from Nova Scotia to Nebraska and along the mountains to northern Georgia.

Texas red oak or spotted oak (*Quercus texana*) furnishes the main supply of red oak lumber in the lower Mississippi Valley.

Pin oak (*Quercus palustris*) ranges from Massachusetts southwesterly to Oklahoma.

Scarlet oak (*Quercus coccinea*) is a northern and northeastern tree, its habitat being bounded westward and southward by Illinois, Tennessee, and North Carolina.

Yellow or black oak (*Quercus velutina*) is found in most States east of the Rocky Mountains, but is more abundant in the North than in the South.

Willow or peach oak (*Quercus phellos*) is of commercial importance in the Southern States only, but it grows naturally as far north as New York.

TABLE 8.—*Oak lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	12,927	3,211,718	100.0
West Virginia	651	408,047	12.7
Tennessee	1,073	386,132	12.0
Arkansas	462	299,809	9.3
Kentucky	1,031	289,406	9.0
Virginia	1,158	255,109	7.9
Ohio	772	207,503	6.5
Missouri	784	197,787	6.2
North Carolina	1,007	172,972	5.4
Pennsylvania	919	166,936	5.2
Indiana	665	151,047	4.7
Mississippi	258	120,365	3.8
Louisiana	94	118,199	3.7
Alabama	383	67,655	2.1
Illinois	269	54,845	1.7
Georgia	328	45,294	1.4
Maryland	196	36,364	1.1
Texas	90	29,335	.9
Wisconsin	334	25,133	.8
New York	871	24,788	.8
South Carolina	158	20,816	.7
Connecticut	160	20,320	.6
Maine	153	16,161	.5
All other States[1]	1,111	97,695	3.0

[1] Includes establishments distributed as follows: California, 5; Delaware, 30; Florida, 7; Iowa, 92; Kansas, 5; Massachusetts, 176; Michigan, 201; Minnesota, 192; Nebraska, 1; New Hampshire, 156; New Jersey, 78 Oklahoma, 79; Oregon, 10; Rhode Island, 14; Vermont, 64; and Washington, 1.

WHITE PINE.

Lumbermen group several pines as white pine in the yards, and one or more of them are reported from 28 States. Two are not the white pines of the botanists, but the lumber frequently passes as such.

White pine (*Pinus strobus*) is the most used and the best known of the white pines. It is the familiar pine of this name of the Lake States, New York, New England, the eastern Canadian Provinces, and of the Appalachian region from Pennsylvania to Georgia. Users often call it soft pine.

Norway pine (*Pinus resinosa*), sometimes called red pine, is lumbered principally in the Lake States, but also farther east. Its range is nearly coextensive with white pine, but it does not follow the mountains much south of New York. Botanically it is closely related to the yellow pines. Certain grades are frequently marked as white pine but the wood has a large market under its own name.

Jack pine (*Pinus divaricata*) is small and of no great importance as lumber, yet it helps to swell the statistics of white pine. It is found from New Brunswick to northern Indiana and Minnesota, and northward almost to the Arctic Circle. It has many local names, among them scrub pine, black pine, and in some parts of Canada has been known as cypress for 200 years.

Western white pine (*Pinus monticola*) is the principal western wood included in the output of white-pine lumber. It occurs from Montana and Idaho to British Columbia and California, but the largest output is at present credited to Idaho. It is occasionally called silver pine.

There are other western pines belonging in the white class, the best known of which is sugar pine, which is separately listed in Table 27, and is discussed on a later page of this report.

TABLE 9.—*White pine lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	4,071	2,568,636	100.0
Minnesota	139	1,027,265	40.0
Wisconsin	382	308,841	12.0
Maine	442	239,303	9.3
Idaho	38	227,845	8.9
New Hampshire	264	181,885	7.1
Massachusetts	280	121,739	4.7
Michigan	230	101,281	3.9
Washington	19	83,974	3.3
New York	1,028	66,201	2.6
Pennsylvania	478	57,102	2.2
North Carolina	162	40,710	1.6
Montana	16	24,606	1.0
Tennessee	113	17,391	0.7
Vermont	108	16,707	0.6
All other States[1]	372	53,786	2.1

[1] Includes establishments distributed as follows: Colorado, 2; Connecticut, 70; Georgia, 21; Indiana, 2; Iowa, 3; Kentucky, 20; Maryland, 10; Ohio, 2; Oregon, 7; Rhode Island, 13; South Carolina, 1; Virginia, 165; West Virginia, 49; and Wyoming, 7.

HEMLOCK.

Practically all of the hemlock that reaches market in the United States comes from one eastern and one western species. The former is known simply as hemlock (*Tsuga canadensis*). It is a northern tree, plentiful from Maine to Minnesota, and following the mountain ranges southward to the Carolinas and Tennessee. The other species is known as western hemlock (*Tsuga heterophylla*) and is found from Montana to the Pacific coast and southward to California. A scarcer western species is the Mountain hemlock (*Tsuga mertensiana*), sometimes called black hemlock. It occurs among the northern Rocky Mountains and westward to the Pacific. The Carolina hemlock (*Tsuga caroliniana*) is likewise a mountain tree and grows in Virginia, North Carolina, South Carolina, and Tennessee. The eastern and the western mountain hemlocks are not extensively lumbered. A reference to the States in Table 10 will reveal the output from the other two.

TABLE 10.—*Hemlock lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	4,035	2,319,982	100.0
Wisconsin	351	664,636	28.7
Michigan	323	440,430	19.0
Pennsylvania	440	328,530	14.2
Washington	105	209,184	9.0
West Virginia	114	205,604	8.9
New York	1,481	121,867	5.3
Maine	355	72,868	3.1
Oregon	32	68,218	2.9
Tennessee	73	42,260	1.8

TABLE 10.—*Hemlock lumber sawed*—Continued.

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
North Carolina	43	37,681	1.6
Vermont	248	30,827	1.3
New Hampshire	183	30,727	1.3
All other States [1]	287	67,150	2.9

[1] Includes establishments distributed as follows: California, 1; Connecticut, 50; Georgia, 2; Idaho, 3; Kentucky, 49; Maryland, 10; Massachusetts, 108; Minnesota, 5; Montana, 3; New Jersey, 3; Ohio, 12; and Virginia, 41.

WESTERN PINE.

Western pine is the western yellow pine (*Pinus ponderosa*) which covers a range of a million square miles from the Rocky Mountains westward to the coast, and northward into Canada and southward into Mexico. It is frequently called California white pine, New Mexico white pine, and western soft pine. It is sufficiently soft and light to make it a strong competitor of white pine for many purposes.

TABLE 11.—*Western pine lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	728	1,258,528	100.0
California	98	317,053	25.2
Oregon	142	216,665	17.2
Washington	141	192,663	15.3
Idaho	113	177,703	14.1
Montana	68	120,414	9.6
Arizona	14	76,346	6.1
New Mexico	28	64,404	5.1
Colorado	54	48,745	3.9
All other States [1]	70	44,535	3.5

[1] Includes establishments distributed as follows: Nevada, 1; South Dakota, 15; Utah, 27; and Wyoming, 27.

CYPRESS.

Bald cypress (*Taxodium distichum*) is the source of the cypress lumber sawed in the United States. It is a southern tree, ranging from Delaware to Texas near the coast, and along the valleys of rivers many miles inland. It follows the Mississippi and the Ohio into Missouri, Illinois, and Indiana.

TABLE 12.—*Cypress lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	607	1,097,247	100.0
Louisiana	94	744,581	67.9
Florida	41	100,723	9.2
Georgia	57	74,818	6.8
South Carolina	43	39,895	3.6
Arkansas	98	35,964	3.3
Missouri	49	28,814	2.6
Mississippi	54	25,782	2.3
North Carolina	62	19,213	1.8
Tennessee	44	14,502	1.3
All other States [1]	65	12,955	1.2

[1] Includes establishments distributed as follows: Alabama, 6; Illinois, 15; Indiana, 2; Kentucky, 17; Maryland, 2; Oklahoma, 2; Texas, 8; and Virginia, 13.

SPRUCE.

While there are a number of spruces largely cut for lumber, two furnish the greater portion. Red spruce (*Picea rubens*) is the principal source of spruce lumber in New England, New York, and West Virginia, while Sitka spruce (*Picea sitchensis*) is lumbered on the northern Pacific coast. In the Northeast black spruce (*Picea mariana*) undoubtedly is cut to a small extent for lumber, while white spruce (*Picea canadensis*) furnishes practically all of the lumber cut in the Lake States. In the Rocky Mountain region Engelmann spruce (*Picea engelmanni*) is the source of spruce lumber. Table 13 shows the production of spruce by States.

TABLE 13.—*Spruce lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	1,547	1,046,816	100.0
Maine	398	371,448	35.5
Washington	63	214,843	20.5
West Virginia	26	134,993	12.9
Oregon	26	74,198	7.1
Vermont	250	52,030	5.0
New Hampshire	127	43,890	4.2
Massachusetts	33	39,198	3.7
New York	325	35,490	3.4
Minnesota	89	31,883	3.1
Colorado	41	13,976	1.3
All other States[1]	169	34,864	3.3

[1] Includes establishments distributed as follows: Arizona, 1; California, 11; Connecticut, 2; Idaho, 7; Kentucky, 1; Michigan, 57; Montana, 17; New Mexico, 7; North Carolina, 2; Pennsylvania, 7; Tennessee, 1; Utah, 7; Virginia, 4; Wisconsin, 33; and Wyoming, 12.

MAPLE.

Several species of maple are cut for lumber in this country, but mills usually report them as one, or, at most, distinguish the wood as hard and soft. Maple lumber in the United States is sawed chiefly from the following species:

Sugar or hard maple (*Acer saccharum*) is more abundant than any other. It grows in all States east of the Mississippi River, and in the first tier of States west of that stream from Minnesota to Texas.

Silver or soft maple (*Acer saccharinum*) has approximately the same range as sugar maple.

Red maple (*Acer rubrum*) is found in all States east of Montana, Wyoming, and Texas.

Eastern species of minor importance are mountain maple (*Acer spicatum*), striped maple (*Acer pennsylvanicum*), and box elder (*Acer negundo*), while the Oregon maple (*Acer macrophyllum*) is cut in the Pacific Coast States.

TABLE 14.—*Maple lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	5,060	901,487	100.0
Michigan	402	402,585	44.7
Wisconsin	359	127,965	14.2
New York	1,172	71,554	8.0
West Virginia	188	69,369	7.7
Pennsylvania	577	58,857	6.5
Ohio	499	36,272	4.0
Indiana	391	29,126	3.2
Vermont	234	27,913	3.1
Missouri	142	11,999	1.3
All other States[1]	1,096	65,847	7.3

[1] Includes establishments distributed as follows: Alabama, 4; Arkansas, 36; Connecticut, 54; Delaware, 5; Georgia, 4; Illinois, 90; Iowa, 42; Kansas, 1; Kentucky, 147; Louisiana, 2; Maine, 159; Maryland, 24; Massachusetts, 86; Minnesota, 33; Mississippi, 14; New Hampshire, 117; New Jersey, 15; North Carolina, 77; Oklahoma, 2; Oregon, 5; Rhode Island, 6; South Carolina, 9; Tennessee, 86; Texas, 2; Virginia, 75; and Washington, 1.

RED GUM.

There is but one red gum (*Liquidambar styraciflua*) in the United States. What is commercially known as "sap gum" is the sapwood of this tree. Its range is in the south, principally in the States of the lower Mississippi Valley; but on the Atlantic coast it grows northward to Connecticut, and in the Mississippi Valley to Missouri and Illinois. Its southwestern limit is in Texas and its southeastern in Florida.

TABLE 15.—*Red gum lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	2,266	772,514	100.0
Arkansas	261	250,055	32.4
Mississippi	165	135,135	17.5
Louisiana	67	61,404	7.9
Missouri	124	59,378	7.7
Tennessee	275	55,620	7.2
North Carolina	167	38,879	5.0
South Carolina	62	31,440	4.1
Kentucky	263	23,943	3.1
Virginia	158	21,315	2.8
Georgia	69	19,367	2.5
Alabama	83	19,013	2.5
Texas	45	13,377	1.7
Florida	13	12,477	1.6
Indiana	182	11,491	1.5
All other States[1]	332	19,620	2.5

[1] Includes establishments distributed as follows: Delaware, 16; Illinois, 91; Maryland, 60; New Jersey, 9; New York, 2; Ohio, 75; Oklahoma, 7; Pennsylvania, 24; and West Virginia, 48.

YELLOW POPLAR.

Yellow poplar (*Liriodendron tulipifera*) is sometimes known as white wood, poplar, or tulip poplar. Its range extends from southern New England to southern Michigan, and southward to Arkansas and Florida. The best growth is found among the mountains of Tennessee, Kentucky, Virginia, and West Virginia.

TABLE 16.—*Yellow poplar lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	4,099	620,176	100.0
West Virginia	393	156,188	25.2
Tennessee	678	112,666	18.2
Kentucky	607	81,207	13.1
Virginia	503	55,537	9.0
North Carolina	462	51,724	8.3
Ohio	311	47,904	7.7
Georgia	162	30,005	4.8
Alabama	148	25,015	4.0
Indiana	263	13,441	2.2
South Carolina	76	12,494	2.0
Pennsylvania	206	11,537	1.9
Mississippi	78	11,281	1.8
All other States[1]	212	11,177	1.8

[1] Includes establishments distributed as follows: Arkansas, 10; Florida, 7; Illinois, 24; Louisiana, 5; Massachusetts, 11; Michigan, 18; Missouri, 12; New Jersey, 25; Connecticut, 33; Delaware, 8; and Maryland, 59.

REDWOOD.

Two closely related trees supply the redwood lumber on the market in this country. Both are confined to California, one in the Sierra Nevada Mountains and the other near the coast. The bigtree (*Sequoia washingtoniana*) is the largest tree species in this country, and that which is commonly known as redwood (*Sequoia sempervirens*) is but little smaller. Most of the lumber is cut from the latter. The whole cut is produced in California, and no tabulated statement is necessary to show it. The total cut in 1913 was 510,271,000 feet.

CHESTNUT.

There is only one species of chestnut (*Castanea dentata*) native in the United States. Its northern range extends from southern Maine to southern Michigan, thence to southern Indiana, central Kentucky, Tennessee, and Alabama. It grows southward in the Atlantic States to Georgia.

TABLE 17.—*Chestnut lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	3,276	505,802	100.0
West Virginia	347	136,283	27.0
Pennsylvania	623	70,696	14.0
Tennessee	342	58,201	11.5
Connecticut	169	47,236	9.3
Virginia	307	46,573	9.2
North Carolina	164	44,129	8.7
Kentucky	234	21,444	4.2
Massachusetts	140	21,226	4.2
New York	577	16,684	3.3
Ohio	145	12,069	2.4
Maryland	90	11,254	2.2
New Jersey	55	10,129	2.0
All other States[1]	83	9,878	2.0

[1] Includes establishments distributed as follows: Alabama, 7; Delaware, 2; Georgia, 8; Indiana, 21; Maine, 1; Michigan, 1; New Hampshire, 27; Rhode Island, 15; and Vermont, 1.

LARCH.

Two species of larch are cut into lumber, but the eastern species is generally called tamarack (*Larix laricina*). The latter is found in the northern tier of States from Minnesota to Maine and in eastern Canada. The western larch (*Larix occidentalis*) is native to Montana, Idaho, Washington, and British Columbia. Both are needle-leaf trees, which annually shed their foliage.

TABLE 18.—*Larch lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	557	395,273	100.0
Montana	49	137,703	34.8
Idaho	50	119,714	30.3
Washington	54	39,277	9.9
Minnesota	112	35,455	9.0
Wisconsin	132	26,008	6.6
Oregon	31	21,228	5.4
Michigan	112	15,721	4.0
All other States [1]	17	167	.0

[1] Includes establishments distributed as follows: Indiana, 1; New Hampshire, 2; New York, 8; Iowa, 2; Maine, 2; Ohio, 1; and Vermont, 1.

BIRCH.

While there are several species of birch in the United States, two furnish the bulk of the lumber produced and the species are seldom separated in the trade. Yellow birch (*Betula lutea*) is the principal source of lumber in New England, New York, and the Lake States, while sweet birch (*Betula lenta*) is the principal species cut in Pennsylvania and West Virginia. The ranges of these species overlap and therefore each is cut to a small extent in the region where the other is most important. In northern New England paper birch (*Betula papyrifera*) is an important source of material for spools, toothpicks, and novelties, but a great deal is not cut into lumber.

Sweet or cherry birch (*Betula lenta*) ranges from Newfoundland to western Ontario and southward into Indiana and Illinois, and among the mountains to Kentucky and Tennessee. It is sometimes known as wintergreen birch.

Yellow birch (*Betula lutea*) has the same eastern range as the foregoing, but extends farther west and northwest.

River birch (*Betula nigra*) ranges over the Southern States, and is found in New England and New York. It is poorer in color and figure than the other birches, but is sometimes cut for lumber.

Paper birch (*Betula papyrifera*) is confined to the northern tier of States east of Minnesota principally, and is very abundant in Michigan, Wisconsin, New York, New England, and Canada.

Mountain birch (*Betula occidentalis*) is sawed in lumber to a moderate extent on the Pacific coast.

White birch (*Betula populifolia*) is a minor timber tree in New England and farther northeast in Canada.

TABLE 19.—*Birch lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	2,218	378,739	100.0
Wisconsin	292	164,612	43.5
Michigan	161	51,814	13.7
Maine	262	40,842	10.8
Vermont	234	31,608	8.3
New York	549	28,569	7.5
West Virginia	67	16,899	4.4
New Hampshire	128	14,732	3.9
Pennsylvania	232	13,152	3.5
Minnesota	71	4,532	1.2
Massachusetts	60	3,733	1.0
Maryland	6	2,553	.7
All other States [1]	156	5,693	1.5

[1] Includes establishments distributed as follows: Arkansas, 3; California, 1; Connecticut, 31; Illinois, 10; Indiana, 11; Iowa, 10; Kentucky, 8; Missouri, 24; New Jersey 3; North Carolina, 20; Ohio, 8; Rhode Island, 1; Tennessee, 9; and Virginia, 17.

BEECH.

There is only one kind of beech native to the United States (*Fagus atropunicea*). It is found in all States east of the Mississippi, and from Missouri southward it is found west of that river. Beech lumber is cut in nearly all the hardwood-producing States.

TABLE 20.—*Beech lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	3,696	365,501	100.0
Michigan	269	86,637	23.7
Indiana	470	54,827	15.0
New York	821	40,313	11.0
Pennsylvania	402	38,700	10.6
West Virginia	182	37,937	10.4
Ohio	492	33,763	9.2
Kentucky	348	26,026	7.1
Vermont	160	14,825	4.1
Tennessee	161	10,268	2.8
New Hampshire	74	6,908	1.9
All other States [1]	317	15,297	4.2

[1] Includes establishments distributed as follows: Alabama, 10; Arkansas, 2; Connecticut, 16; Georgia, 2; Illinois, 25; Iowa, 3; Louisiana, 3; Maine, 71; Maryland, 16; Massachusetts, 35; Minnesota, 2; Mississippi, 7; Missouri, 4; New Jersey, 3; North Carolina, 34; Rhode Island, 1; Texas, 3; Virginia, 53; and Wisconsin, 27.

CEDAR.

A number of species contributing to the country's lumber supply are grouped under the common name cedar, though the relationship between some of them is not very close.

Incense cedar (*Libocedrus decurrens*) grows among the mountains of Oregon and California.

Port Orford cedar (*Chamæcyparis lawsoniana*) is confined to a restricted area of northwestern California and southwestern Oregon.

Yellow cedar (*Chamæcyparis nootkatensis*) is a Pacific coast species extending from Alaska southward through British Columbia into Washington.

Red cedar (*Juniperus virginiana*) ranges through nearly the whole region east of the Rocky Mountains in the United States.

There are no fewer than 10 closely related cedars, usually called junipers, most of them being native to the Rocky Mountain region and farther west.

Northern white cedar (*Thuja occidentalis*), often called arborvitæ, is most abundant in the Lake States, but it extends to New England and southward along the Appalachian Mountains to eastern Tennessee.

Western red cedar (*Thuja plicata*) is much more used for shingles than for lumber in the States of Washington, Oregon, Idaho, and Montana, where the chief supply grows. It is called giant cedar and western cedar in commerce.

Southern white cedar (*Chamæcyparis thyoides*) ranges in deep swamps from New Jersey to Florida, and is called swamp cedar in some parts of its range and juniper in others. All cedars are valuable for poles and posts, and some of them are more used for these purposes than for lumber.

The most important contributions to the lumber supply are the following: Western red cedar (*Thuja plicata*), northern white cedar (*Thuja occidentalis*), and southern white cedar (*Chamæcyparis thyoides*). Red cedar (*Juniperus virginiana*) is of considerable importance as a material for pencils. In the Pacific Coast States incense cedar (*Libocedrus decurrens*), Port Orford cedar (*Chamæcyparis lawsoniana*), and yellow cedar (*Chamæcyparis nootkatensis*) are lumbered to a small extent.

TABLE 21.—*Cedar lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	508	358,444	100.0
Washington	122	233,443	65.1
Idaho	12	23,307	6.5
California	28	22,056	6.2
Oregon	51	21,902	6.1
Virginia	7	16,558	4.6
Tennessee	44	7,982	2.2
Maine	46	7,005	2.0
North Carolina	59	5,167	1.5
Wisconsin	20	4,403	1.2
Kentucky	11	2,202	.6
All other States [1]	108	14,419	4.0

[1] Includes establishments distributed as follows: Alabama, 1; Arkansas, 3; Connecticut, 5; Delaware, 2; Indiana, 1; Maryland, 5; Massachusetts, 12; Michigan, 18; Minnesota, 11; Missouri, 2; Montana, 2; New Hampshire, 1; New Jersey, 21; New York, 4; Pennsylvania, 1; Rhode Island, 1; South Carolina, 7; Texas, 1; Vermont, 5; and West Virginia, 2.

BASSWOOD.

Three kinds of basswood contribute to the lumber cut of the country, but no distinction between them is made at the mill or in the market. Common basswood (*Tilia americana*) is best developed in the Lake States, white basswood (*Tilia hetrophylla*) among the mountain ranges in West Virginia and southward, and downy basswood (*Tilia pubescens*) is found, though scarce, from North Carolina

to Arkansas. All three of these overlap the boundaries here named, and in some regions all are found occupying the same area. At least one-half of the States furnish basswood logs for sawmills.

TABLE 22.—*Basswood lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	3,336	257,102	100.0
Wisconsin	375	91,670	35.7
Michigan	277	39,265	15.3
West Virginia	165	31,623	12.3
New York	1,183	24,818	9.6
Ohio	205	8,784	3.4
Tennessee	99	8,703	3.4
Kentucky	130	8,404	3.3
Minnesota	124	8,084	3.1
Virginia	74	6,231	2.4
North Carolina	65	6,180	2.4
Indiana	121	5,615	2.2
Vermont	128	5,317	2.1
Pennsylvania	174	5,237	2.0
All other States [1]	216	7,171	2.8

[1] Includes establishments distributed as follows: Alabama, 7; Arkansas, 1; Connecticut, 14; Georgia, 3; Illinois, 12; Iowa, 46; Kansas, 1; Louisiana, 2; Maine, 56; Maryland, 10; Massachusetts, 17; Mississippi, 2; Missouri, 23; New Hampshire, 17; New Jersey, 2; and Texas, 3.

ELM.

Lumbermen recognize soft and rock elm, the latter name being frequently applied to tough wood cut from any elm species. Soft gray or white elm (*Ulmus americana*) is most widely dispersed and is more abundant than all the others combined. It is found in all States east of the Rocky Mountains and furnishes the large part of the elm lumber reported.

Cork or the true rock elm (*Ulmus racemosa*) is found growing across the northern States from New England to Nebraska and as far south as Missouri and Tennessee.

Slippery elm (*Ulmus pubescens*) covers the eastern half of the United States, but is nowhere plentiful. It is often called red elm.

Wing elm (*Ulmus alata*) and cedar elm (*Ulmus crassifolia*) are confined to the States of the lower Mississippi.

TABLE 23.—*Elm lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	3,034	214,532	100.0
Wisconsin	315	52,307	24.4
Michigan	305	45,415	21.2
Indiana	307	20,624	9.6
Ohio	322	19,345	9.0
Missouri	243	13,648	6.4
Arkansas	69	11,815	5.5
New York	758	11,016	5.1
Tennessee	124	9,219	4.3
Mississippi	43	6,750	3.1
Minnesota	35	5,752	2.7
Kentucky	93	3,760	1.8
Illinois	126	3,656	1.7
Iowa	82	3,263	1.5
Louisiana	22	2,860	1.3
All other States [1]	190	5,102	2.4

[1] Includes establishments distributed as follows: Alabama, 6; Connecticut, 7; Georgia, 5; Kansas, 4; Maine, 13; Maryland, 2; Massachusetts, 8; Nebraska, 1; New Hampshire, 4; New Jersey, 4; North Carolina, 11; Oklahoma, 16; Pennsylvania, 48; South Carolina, 4; Texas, 9; Vermont, 34; Virginia, 5; and West Virginia, 9.

COTTONWOOD.

Cottonwood lumber is cut from a group of trees which are known under various names in the regions where they grow. Among them are the common cottonwood, balm of Gilead, and aspen or popple, which are the most important east of the Rocky Mountains, and black cottonwood on the Pacific coast.

Common cottonwood (*Populus deltoides*) furnishes the bulk of the lumber. It is found in the whole country east of the Rocky Mountains and is lumbered in all parts of its range.

Swamp cottonwood (*Populus hetrophylla*) is best developed in the lower Mississippi Valley States, but it grows naturally in the Atlantic States and in the Ohio Valley.

Aspen or popple (*Populus tremuloides*) is often designated as poplar in the Lake States, where much of it grows. It is found growing in various localities from Maine to California and far northward in British America. Saw logs cut from aspen are usually small.

Large-toothed aspen (*Populus grandidentata*) is not usually distinguished from the other. It ranges from Nova Scotia to Minnesota and along the mountains to Tennessee and North Carolina.

Balm of Gilead (*Populus balsamifera*) is commonly known as balm in the factory and lumberyard. Its range includes Maine and Oregon and most of the States between, and also a large part of British America.

Western or black cottonwood (*Populus trichocarpa*) ranges near the Pacific coast from Alaska to southern California. It is the largest of the cottonwoods.

Small quantities of lumber are cut from two foreign cottonwoods which have been introduced in this country, the white poplar (*Populus alba*), also called silver and English poplar, and the black or lombardy poplar (*Populus nigra*).

TABLE 24.—*Cottonwood lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	1,004	208,938	100.0
Arkansas	48	61,345	29.4
Mississippi	39	58,395	27.9
Louisiana	29	23,126	11.1
Tennessee	21	12,314	5.9
Minnesota	96	8,186	3.9
Texas	11	7,425	3.5
Missouri	103	7,175	3.4
Iowa	79	4,575	2.2
Michigan	45	3,095	1.5
Oklahoma	20	2,634	1.3
Florida	3	2,396	1.1
Kentucky	13	2,066	1.0
All other States[1]	497	16,206	7.8

[1] Includes establishments distributed as follows: Alabama, 2; Colorado, 2; Connecticut, 4; Georgia, 2; Idaho, 4; Illinois, 37; Indiana, 38; Kansas, 4; Maine, 29; Maryland, 1; Massachusetts, 7; Montana, 5; Nebraska, 2; New Hampshire, 13; New York, 202; North Carolina, 3; Ohio, 36; Oregon, 3; Pennsylvania, 3; South Carolina, 4; Utah, 5; Vermont, 48; Washington, 3; and Wisconsin, 40.

ASH.

Of more than a dozen species of ash growing in the United States three kinds of ash are important sources of lumber. White ash (*Fraxinus americana*) is the most valuable and is cut mostly in the central hardwood States and Northeast and to some extent in the Lake States. A great deal of the ash lumber cut in the Lake States comes from the black ash (*Fraxinus nigra*), while the same species is cut to considerable extent in the Northeast. Green ash (*Fraxinus lanceolata*) is the principal source of ash lumber in the Southern States. In the Pacific Coast States Oregon ash (*Fraxinus oregona*) is sometimes cut, while red ash (*Fraxinus pennsylvanica*) is used to a limited extent in the East.

TABLE 25.—*Ash lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	3,348	207,816	100.0
Arkansas	92	31,019	14.9
Tennessee	170	22,943	11.0
Louisiana	47	17,473	8.4
Indiana	233	15,517	7.5
Ohio	295	12,967	6.2
Wisconsin	184	12,858	6.2
Missouri	87	10,969	5.3
New York	927	9,928	4.8
Mississippi	65	9,914	4.8
West Virginia	82	9,761	4.7
Kentucky	161	9,066	4.3
Michigan	184	8,681	4.2
Pennsylvania	186	5,742	2.8
Maine	92	3,514	1.7
Texas	20	3,371	1.6
Georgia	23	3,088	1.5
All other States [1]	500	21,005	10.1

[1] Includes establishments distributed as follows: Alabama, 18; California, 1; Connecticut, 51; Delaware, 1; Florida, 8; Illinois, 41; Iowa, 14; Kansas, 1; Maryland, 6; Massachusetts, 32; Minnesota, 67; New Hampshire, 21; New Jersey, 6; North Carolina, 65; Oklahoma, 17; Oregon, 4; Rhode Island, 6; South Carolina, 13; Vermont, 90; and Virginia, 38.

HICKORY.

Ten or more kinds of hickory are cut in this country, and the trees grow naturally nowhere else in the world. The wood of all species is valuable, but most of that in use is cut from five or six species, which are shagbark (*Hicoria ovata*), shellbark (*Hicoria laciniosa*), pignut (*Hicoria glabra*), bitternut (*Hicoria minima*), and mockernut (*Hicoria alba*). One or more of these hickories are found in every State in the eastern part of the United States, and the wood is also abundant in Missouri and Arkansas. The hickory growing in the Ohio Valley and along tributary streams supplies the bulk of that in use. The industries which use the largest quantities of hickory secure it in the form of blanks, squares, or billets, rather than in the form of lumber.

TABLE 26.—*Hickory lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	2,579	162,980	100.0
Arkansas	138	26,750	16.4
Tennessee	225	26,678	16.4
Kentucky	217	17,583	10.8
Ohio	362	15,545	9.5
Indiana	301	12,919	7.9
Louisiana	22	10,639	6.5
Mississippi	48	10,625	6.5
West Virginia	148	9,262	5.7
Missouri	159	8,020	4.9
Illinois	120	5,124	3.2
Pennsylvania	192	4,578	2.8
All other States [1]	647	15,257	9.4

[1] Includes establishments distributed as follows: Alabama, 35; Connecticut, 52; Delaware, 3; Florida, 2; Georgia, 28; Iowa, 22; Kansas, 3; Maine, 1; Maryland, 20; Massachusetts, 5; Michigan, 26; Minnesota, 4; New Hampshire, 1; New Jersey, 16; New York, 255; North Carolina, 77; Oklahoma, 11; Rhode Island, 2; South Carolina, 6; Texas, 9; Virginia, 64; and Wisconsin, 5.

SUGAR PINE.

Sugar pine (*Pinus lambertiana*), the largest pine in the United States, grows in California and Oregon, chiefly in the former State. The wood closely resembles white pine, and the uses of the two are similar. Botanically it is a white or soft pine.

TABLE 27.—*Sugar pine lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	45	149,926	100.0
California	40	147,023	98.1
Oregon	5	2,903	1.9

TUPELO.

Four species contribute to the output of tupelo lumber, but the bulk of the product is cut from cotton gum (*Nyssa aquatica*). It is a tree which flourishes best in deep swamps in the coast region of the Southern States or along the lowlands of large rivers from southern Virginia to Texas.

Water gum (*Nyssa biflora*), ranging from Maryland to Florida and west to Alabama, and sour tupelo or wild limetree (*Nyssa ogeche*), found in South Carolina, Georgia, and Florida, are cut for lumber to a small extent.

Black gum or pepperidge (*Nyssa sylvatica*) ranges throughout the South and northward to Maine and Michigan, and is cut in North Carolina, Virginia, and other States north of the Ohio and Potomac Rivers.

TABLE 28.—*Tupelo lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	241	120,420	100.0
Louisiana	47	71,046	59.0
North Carolina	24	10,726	8.9
Alabama	9	8,835	7.3
Florida	9	7,603	6.3
South Carolina	16	5,461	4.9
Virginia	10	5,202	4.3
Illinois	7	3,063	2.6
All other States [1]	119	8,484	7.1

[1] Includes establishments distributed as follows: Arkansas, 14; Connecticut, 1; Georgia, 6; Indiana, 11; Kentucky, 17; Mississippi, 15; Missouri, 9; Ohio, 6; Pennsylvania, 1; Tennessee, 26; Texas, 2, and West Virginia, 11.

BALSAM FIR.

One species furnishes practically all of the balsam-fir lumber produced. This species is the common balsam (*Abies balsamea*), which is lumbered in the Northeast, in Pennsylvania, and in the Lake States. This species is also cut in the southern Appalachian Mountains with frazer fir (*Abies fraseri*).

TABLE 29.—*Balsam fir lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	509	93,752	100.0
Maine	243	67,007	71.5
Minnesota	76	10,058	10.7
Vermont	73	5,896	6.3
Michigan	40	4,113	4.4
New Hampshire	28	3,148	3.4
Wisconsin	34	2,764	2.9
All other States [1]	15	766	.8

[1] Includes establishments distributed as follows: Illinois, 1; Massachusetts, 4; and New York, 10.

WHITE FIR.

White fir (*Abies concolor*) is a distinct botanical species growing in practically all of the Western States and is the principal source of commercial white-fir lumber. Other species reported by sawmills under the same name are grand fir (*Abies grandis*), lovely fir (*Abies amabilis*), noble fir (*Abies nobilis*), and red fir (*Abies magnifica*).

TABLE 30.—*White fir lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	126	88,109	100.0
California	36	47,695	54.1
Idaho	25	28,231	32.0
Oregon	25	7,735	8.8
Montana	6	2,330	2.7
Washington	13	1,323	1.5
All other States [1]	21	795	0.9

[1] Includes establishments distributed as follows: Arizona, 1; Colorado, 6; New Mexico, 1; Utah, 8; and Wyoming, 5.

WALNUT.

Although three walnut trees, exclusive of butternut, are native of the United States, the whole of the walnut lumber is cut from the common black walnut (*Juglans nigra*), which abounds throughout the eastern half of the country, extending from the Atlantic to the edge of the treeless plains west of the Mississippi River. The small Mexican walnut (*Juglans rupestris*) grows in Texas, and another, which is also small, is the California walnut (*Juglans californica*).

TABLE 31.—*Walnut lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	895	40,565	100.0
Indiana	191	10,194	25.1
Ohio	107	7,164	17.6
Missouri	114	7,047	17.4
Tennessee	94	3,926	9.7
Illinois	31	3,890	9.6
Kentucky	110	3,450	8.5
Arkansas	10	2,064	5.1
All other States [1]	238	2,830	7.0

[1] Includes establishments distributed as follows: Alabama, 3; Connecticut, 2; Georgia, 2; Iowa, 27; Kansas, 3; Maryland, 8; Massachusetts, 5; Michigan, 9; Minnesota, 2; Nebraska, 1; New Jersey, 1; New York, 5; North Carolina, 27; Oklahoma, 10; Pennsylvania, 30; Rhode Island, 2; South Carolina, 1; Texas, 4; Virginia, 40; West Virginia, 50; and Wisconsin, 6.

SYCAMORE.

A single species of sycamore (*Platanus occidentalis*) furnishes the lumber of this name in the United States. It ranges from southern New England to Nebraska and southward to the Gulf of Mexico. One small species of sycamore in Arizona and another in California are seldom sawed for lumber.

TABLE 32.—*Sycamore lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	659	30,804	100.0
Arkansas	31	11,663	37.9
Missouri	140	3,840	12.5
Tennessee	37	3,586	11.6
Indiana	129	3,519	11.4
Kentucky	84	2,652	8.6
Ohio	70	2,018	6.6
Illinois	64	1,309	4.2
All other States [1]	104	2,217	7.2

[1] Includes establishments distributed as follows: Alabama, 2; Connecticut, 3; Georgia, 6; Iowa, 2; Kansas, 3; Louisiana, 3; Maryland, 5; Michigan, 7; Mississippi, 4; New Jersey, 1; New York, 3; North Carolina, 17; Oklahoma, 15; Pennsylvania, 7; South Carolina, 3; Texas, 1; Virginia, 14; and West Virginia, 8.

LODGEPOLE PINE.

Lodgepole pine (*Pinus contorta*) is a slow-growing tree dispersed over much of the regions between the Rocky Mountains and the Pacific coast. It is inclined to take possession of tracts laid bare by fire, where it grows in heavy stands.

TABLE 33.—*Lodgepole pine lumber sawed.*

State.	Number of active mills reporting.	Quantity (M feet b. m.).	Per cent of distribution.
United States	82	20,106	100.0
Colorado	19	10,410	51.8
Wyoming	27	6,998	34.8
Montana	16	1,199	6.0
Idaho	16	1,009	5.0
Utah	4	490	2.4

MINOR SPECIES.

Some of the species listed in Table 34 are native, others foreign. Logs of the latter are brought to this country and are converted into lumber at sawmills located in the States designated in the table.

Mahogany (*Swietenia mahagoni*) comes from tropical America. Other woods passing for mahogany come from Africa, South America, India, and the Philippines.

Cherry (*Prunus serotina*) grows in western New York, Pennsylvania, and southward among the mountains, and westward to the States beyond the Mississippi.

Buckeye (*Æsculus octandra*) is the common tree cut for lumber of this name. It is often known as yellow buckeye. Ohio buckeye (*Æsculus glabra*) is occasionally cut for lumber; but the buckeye lumber frequently goes to market as "poplar saps," or as the sapwood of yellow poplar.

Locust (*Robinia pseudacacia*) has been widely planted, but its natural range lies in the region from Pennsylvania to Georgia. Honey locust (*Gleditsia tricanthos*) and water locust (*Gleditsia aquatica*) are sometimes listed as locust lumber in mill yards. Both are most plentiful south of the Ohio River and west of the mountains.

Black willow (*Salix nigra*) is the principal one of several willows occasionally sawed into lumber. It is best developed in the lower Mississippi Valley.

Cucumber (*Magnolia acuminata*) occurs from New York to Illinois and south to Alabama and Arkansas.

Magnolia (*Magnolia fœtida*) is the tree known in the South as evergreen or laurel-leafed magnolia. The magnolia lumber of commerce is usually cut from this species, though there are three or four kindred species in the South which are sawed in small amounts.

Hackberry (*Celtis occidentalis*) and sugarberry (*Celtis mississippiensis*) are listed without distinction as hackberry lumber. Both occur in the lower Mississippi Valley States and westward, and hackberry is scattered over most of the United States east of the Rocky Mountains, but in many regions is very scarce.

Butternut (*Juglans cinerea*) ranges from New Brunswick to Georgia and from Dakota to Arkansas.

Persimmon (*Diospyros virginiana*) is found chiefly in the Southern States, but it grows northward to Kansas and Connecticut.

Dogwood (*Cornus florida*) is too small for saw logs, but is cut into billets suitable for shuttle makers. The principal supply comes from Tennessee, Kentucky, the Carolinas, and Virginia, but its range covers the eastern half of the United States.

Pecan (*Hicoria pecan*) is a hickory with wood inferior to the commercial hickories. It is a southern species more valuable for nuts than lumber.

Ebony is foreign. Several trees belonging to the same family as persimmon produce the wood.

Two alders are sawed for lumber—red alder (*Alnus oregona*) and white alder (*Alnus rhombifolia*)—both native of the Pacific coast.

Applewood is cut from many varieties of apple of planted stock.

Bois d'Arc, or Osage orange (*Toxylon pomiferum*), has been widely planted, but its native home is in Texas and Oklahoma.

Chinquapin (*Castanea pumila*) ranges from Pennsylvania to Florida and westward to Texas. Sometimes lumber which is listed as chinquapin is chinquapin oak (*Quercus acuminata*), which occupies much the same range.

Coffeetree (*Gymnocladus dioicus*) is found scattered over much of the eastern half of the United States, but is most abundant in Kentucky and Tennessee.

Crabapple is a term applied to a number of species in the eastern half of the country, but the sweet crab (*Pyrus coronaria*) is the best known.

Eucalyptus (*Eucalyptus globulus*) is an Australian tree which is growing successfully from plantings in California. More than 50 other species of eucalyptus are growing in California, several of which are sometimes converted into timber locally.

Hornbeam (*Ostrya virginiana*) is found from Nova Scotia to Texas.

Ironwood is a term applied to so many woods, both domestic and foreign, that the word is meaningless in determining the species referred to. It is often applied to lignum-vitæ.

Jenisero, prima vera, and white mahogany (*Tabebuia donnell-smithii*) are different names for the same species, which grows in southern Mexico and Central America.

Mulberry (*Morus rubra*) ranges through most of the eastern half of the United States.

Madrona (*Arbutus menziesii*) is a tree of the Pacific Coast States.

Sassafras (*Sassafras sassafras*) is native from Massachusetts to Texas, but is best developed in Tennessee, Kentucky, and Arkansas.

Silverbell (*Mohrodendron carolinum*) is found in the mountains of West Virginia and southward and westward to Florida and Texas.

TABLE 34.—*Minor species of lumber.*

Kind.	Quantity sawed (M feet b. m.).	Principal States reporting.
Total	85,366	
Mahogany	36,261	California, Illinois, Indiana, Kentucky, Louisiana, Massachusetts, Missouri, Ohio, and Pennsylvania.
Cherry	14,126	Alabama, Arkansas, Connecticut, Illinois, Indiana, Iowa, Kentucky, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, New Jersey, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, Tennessee, Vermont, Virginia, West Virginia, and Wisconsin.
Buckeye	6,422	Illinois, Indiana, Iowa, Kentucky, Missouri, North Carolina, Ohio, Tennessee, Virginia, and West Virginia.
Locust	5,507	Alabama, Arkansas, Illinois, Indiana, Kentucky, Maryland, Mississippi, Missouri, New York, North Carolina, Pennsylvania, South Carolina, Tennessee, Virginia, and West Virginia.
Willow	4,753	Arkansas, Indiana, Iowa, Kentucky, Louisiana, Minnesota, Mississippi, Missouri, New York, Ohio, Pennsylvania, Texas, and Wisconsin.
Cucumber	3,424	Kentucky, Maryland, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia.
Magnolia	3,268	Georgia, Louisiana, Mississippi, and Texas.
Hackberry	2,115	Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Minnesota, Mississippi, Missouri, Oklahoma, and Tennessee.
Butternut	1,964	Connecticut, Indiana, Iowa, Kentucky, Massachusetts, Michigan, Minnesota, Missouri, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Vermont, Virginia, West Virginia, and Wisconsin.
Persimmon	1,904	Arkansas, Indiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, and Virginia.
Dogwood	1,373	Arkansas, North Carolina, South Carolina, and Virginia.
Pecan	1,090	Arkansas, Illinois, Indiana, Kentucky, Louisiana, Mississippi, Missouri, Oklahoma, and Texas.
Ebony	1,000	Illinois.
All other kinds[1]	2,159	Alabama, Arkansas, California, Connecticut, Indiana, Kentucky, Louisiana, Massachusetts, Michigan, Missouri, New Jersey, New York, North Carolina, Pennsylvania, Oklahoma, Oregon, Tennessee, and Washington.

[1] Includes alder, apple, bois d'arc, chinquapin, coffeetree, crabapple, eucalyptus, hornbeam, ironwood, jenisero, madrona, mulberry, sassafras, silverbell, and Spanish cedar.

DETAILED SUMMARY.

Table 35 brings together all the figures which have been presented regarding the production of lumber, and shows separately for hardwoods and softwoods the amounts of each kind of wood cut in each State, together with totals for each kind of wood and each State.

TABLE 35.—*Number of active lumber mills reporting and quantity of lumber sawed (M feet b. m.), by States, 1913.*

State.	Number of active mills reporting.	Aggregate.	Softwoods.														
			Total	Yellow pine.	Douglas fir.	White pine.	Hemlock.	Western pine.	Cypress.	Spruce.	Redwood.	Larch (tamarack).	Cedar.	Sugar pine.	Balsam fir.	White fir.	Lodgepole pine.
Alabama	816	1,523,936	1,398,005	1,395,059					1,941				1,005				
Arizona	14	77,368	77,363		680			76,346		112						225	
Arkansas	808	1,911,647	1,210,570	1,174,498					35,964				108				
California	141	1,183,380	1,178,768		132,176		680	317,053		1,814	510,271		22,056	147,023		47,695	
Colorado	89	74,602	74,356		942	250		48,745		13,976						33	10,410
Connecticut	177	93,730	18,125	1,393		11,626	4,931			75			100				
Delaware	44	18,039	13,764	13,753									11				
Florida	203	1,055,047	1,024,596	923,873					100,723								
Georgia	688	844,284	740,039	662,043		3,123	55		74,818								
Idaho	161	652,616	651,736		67,112	227,845	6,505	177,703		310		119,714	23,307			28,231	1,009
Illinois	275	102,902	4,510	410					3,965						135		
Indiana	695	332,993	239	17		9			185			20	8				
Iowa	111	21,676	5,045	22		5,016						7					
Kansas	6	509															
Kentucky	1,061	541,531	36,644	20,572		1,151	11,456		1,218	45			2,202				
Louisiana	408	4,161,560	3,836,956	3,092,375					744,581								
Maine	686	834,673	759,754	2,023		239,303	72,868			371,448		100	7,005		67,007		
Maryland	258	140,469	75,140	65,143		303	9,048		510				136				
Massachusetts	312	224,580	176,555	2,491		121,739	12,377			39,198			480		270		
Michigan	532	1,222,983	572,218			101,281	440,430			9,791		15,721	882		4,113		
Minnesota	354	1,149,704	1,106,911			1,027,265	475			31,883		35,455	1,775		10,058		
Mississippi	679	2,610,581	2,250,493	2,224,711					25,782								
Missouri	844	416,608	93,778	57,023					28,814				7,941				
Montana	109	357,974	357,747		63,494	24,606	298	120,414		7,623		137,703	80			2,330	1,199
New Hampshire	305	309,424	261,973	2,310		181,885	30,727			43,890		3	10		3,148		
New Jersey	94	27,248	8,564	7,184			275						1,105				
New Mexico	28	65,818	65,818		51			64,404		1,344						19	
New York	1,917	457,720	223,968			66,201	121,867			35,493		24	22		361		
North Carolina	1,531	1,957,258	1,617,973	1,515,102		40,710	37,681		19,213	100			5,167				
Ohio	826	414,943	2,933	1,150		120	1,660					3					
Oklahoma	113	140,284	120,927	120,860					67								
Oregon	406	2,098,467	2,090,592		1,675,391	2,352	68,218	216,665		74,198		21,228	21,902	2,903		7,735	
Pennsylvania	1,159	781,547	401,090	15,271		57,102	328,530			159			28				
Rhode Island	15	14,984	5,240	785		4,430							25				
South Carolina	497	752,184	675,550	635,426		10			39,895				219				
South Dakota	15	19,103	19,103					19,103									
Tennessee	1,155	872,311	144,572	60,137		17,391	42,260		14,502	2,300			7,982				
Texas	341	2,081,471	2,025,984	2,024,231					1,748				5				
Utah	39	5,403	5,337		258			3,619		577						393	490
Vermont	363	194,647	106,335	476		16,707	30,827			52,030		10	389		5,896		

Virginia	1,574	1,273,953	864,008	810,362	....	14,077	19,390	....	3,321	300	....	....	16,558	....	....	....
Washington	469	4,592,053	4,590,137	....	3,615,430	83,974	209,184	192,663	....	214,843	....	39,277	233,443	....	....	1,323	....
West Virginia	678	1,249,559	362,025	10,663	....	10,675	205,604	....	....	134,993	....	....	90	....	....	....	....
Wisconsin	612	1,493,353	1,015,591	....	....	308,841	664,636	....	....	8,939	....	26,008	4,403	....	2,764	....	....
Wyoming	57	12,940	12,940	....	562	644	....	3,236	....	1,375	....	....	....	....	....	125	6,998
All other States[1]	3	18,952	18,577	....	....	....	....	18,577	....	....	....	....	....	....	....	....	....
United States	21,668	38,387,009	30,302,549	14,839,363	5,556,096	2,568,636	2,319,982	1,258,528	1,097,247	1,046,816	510,271	395,273	358,444	149,926	93,752	88,109	20,106

State.	Hardwoods.															
	Total.	Oak.	Maple.	Red gum.	Yellow poplar.	Chestnut.	Birch.	Beech.	Basswood.	Elm.	Cottonwood.	Ash.	Hickory.	Tupelo.	Walnut.	Sycamore.	Minor species.
Alabama	125,931	67,655	44	19,013	25,015	216	....	272	141	179	1,879	1,394	1,206	8,835	27	33	22
Arkansas	701,077	299,809	2,720	250,055	266	....	37	3	10	11,815	61,345	31,019	26,750	605	2,064	11,663	2,916
California	4,612	3,481	....	....	....	....	350	....	....	....	....	350	....	....	....	....	431
Colorado	246	....	....	....	....	....	....	....	....	....	246	....	....	....	....	....	....
Connecticut	75,605	20,320	2,384	....	1,032	47,236	1,291	656	394	47	83	754	1,228	3	4	125	48
Delaware	4,275	2,855	146	879	153	80	....	....	....	....	....	50	112	....	....	....	....
Florida	30,451	3,262	....	12,477	1,571	....	....	....	....	....	2,396	2,042	1,100	7,603	....	....	....
Georgia	104,245	45,294	310	19,367	30,005	1,250	....	70	300	306	200	3,088	2,465	1,250	5	315	20
Idaho	880	....	....	....	....	....	....	....	....	....	880	....	....	....	....	....	....
Illinois	98,392	54,845	2,517	7,409	1,889	....	81	1,826	118	3,656	1,660	1,860	5,124	3,063	3,890	1,309	9,145
Indiana	332,754	151,047	29,126	11,491	13,441	758	161	54,827	5,615	20,624	514	15,517	12,919	705	10,194	3,519	2,296
Iowa	16,631	5,630	806	....	....	....	94	35	1,296	3,263	4,557	138	247	....	290	8	249
Kansas	509	142	1	....	....	....	....	....	8	91	94	7	53	....	81	27	5
Kentucky	504,887	289,406	5,730	23,943	81,207	21,444	111	26,026	8,404	3,760	2,066	9,066	17,583	312	3,450	2,652	9,727
Louisiana	324,604	118,199	121	61,404	605	....	....	349	102	2,860	23,126	17,473	10,639	71,046	....	143	18,537
Maine	74,919	16,161	8,420	....	....	430	40,842	2,385	1,578	85	1,494	3,514	10	....	....	....	....
Maryland	65,329	36,364	2,923	2,447	4,476	11,254	2,553	2,256	1,978	35	5	92	727	....	33	52	134
Massachusetts	48,025	11,106	4,521	....	420	21,226	3,733	2,710	311	56	200	881	71	....	70	....	2,720
Michigan	650,765	11,447	402,585	....	194	10	51,814	86,637	39,265	45,415	3,095	8,681	545	....	31	67	979
Minnesota	42,793	14,163	497	....	....	....	4,532	30	8,084	5,752	8,186	1,480	22	....	9	....	38
Mississippi	360,088	120,365	588	135,135	11,281	....	....	228	28	6,750	58,395	9,914	10,625	1,849	....	25	4,905
Missouri	322,830	197,787	11,999	59,378	223	....	280	35	204	13,648	7,175	10,969	8,020	1,110	7,047	3,840	1,115
Montana	227	....	....	....	....	....	....	....	....	....	227	....	....	....	....	....	....
New Hampshire	47,451	11,740	9,859	....	....	2,122	14,732	6,908	576	8	503	903	100	....	....	....	....
New Jersey	18,684	7,352	171	187	348	10,129	21	73	12	35	....	60	256	....	2	15	23
New York	233,752	24,788	71,554	29	....	16,684	28,569	40,313	24,818	11,016	1,365	9,928	1,298	....	12	5	3,373
North Carolina	339,285	172,972	5,394	38,879	51,724	44,129	997	825	6,180	760	335	2,649	2,266	10,726	305	141	1,003
Ohio	412,010	207,503	36,272	2,338	47,904	12,069	87	33,763	8,784	19,345	678	12,967	15,545	261	7,164	2,018	5,312
Oklahoma	19,357	11,868	25	2,232	....	....	....	....	....	363	2,634	706	611	....	84	413	421
Oregon	7,875	6,499	685	....	....	....	....	....	....	....	50	146	....	....	....	....	495
Pennsylvania	380,457	166,936	58,857	218	11,537	70,696	13,152	38,700	5,237	830	22	5,742	4,578	40	234	202	3,476
Rhode Island	9,744	4,080	315	....	....	4,982	50	10	....	....	....	152	115	....	40	....	....

[1] Includes Nebraska and Nevada.

TABLE 35.—*Number of active lumber mills reporting and quantity of lumber sawed (M feet b. m.), by States, 1913*—Continued.

State.	Hardwoods.																
	Total.	Oak.	Maple.	Red gum.	Yellow poplar.	Chestnut.	Birch.	Beech.	Basswood.	Elm.	Cottonwood.	Ash.	Hickory.	Tupelo.	Walnut.	Sycamore.	Minor species.
South Carolina	76,634	20,816	813	31,440	12,494					422	1,509	2,862	444	5,461	1	190	182
Tennessee	727,739	386,132	9,606	55,620	112,666	58,201	1,176	10,268	8,703	9,219	12,314	22,943	26,678	1,667	3,926	3,586	5,034
Texas	55,487	29,335	14	13,377				170	115	792	7,425	3,371	469	150	53	5	211
Utah	66										66						
Vermont	88,312	3,964	27,913			30	31,608	14,825	5,317	483	1,082	2,990					100
Virginia	409,945	255,109	7,207	21,315	55,537	46,573	957	1,681	6,231	22		1,489	1,877	5,202	571	177	5,997
Washington	1,916	6	30								1,850						30
West Virginia	887,534	408,047	69,369	3,881	156,188	136,283	16,899	37,937	31,623	488		9,761	9,262	532	916	274	6,074
Wisconsin	477,762	25,133	127,965				164,612	1,683	91,670	52,307	1,114	12,858	35		37		348
All other States [1]	375	100								100	150				25		
United States	8,084,460	3,211,718	901,487	772,514	620,176	505,802	378,739	365,501	257,102	214,532	208,938	207,816	162,980	120,420	40,565	30,804	85,366

[1] Includes Nebraska and Nevada.

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Contribution from the Bureau of Entomology, L. O. Howard, Chief.
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RELATION OF THE ARIZONA WILD COTTON WEEVIL TO COTTON PLANTING IN THE ARID WEST.[1]

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INTRODUCTION.

With the introduction of cotton culture into Arizona under conditions of irrigation, it was hoped that the establishment of important insect pests could be prevented by quarantines, and this was rendered possible by the complete isolation of the new territory. Recent investigations in Arizona, however, have revealed the presence of a weevil, *Anthonomus grandis thurberiæ,* very nearly identical with the famous Mexican cotton-boll weevil which has proved so disastrous to cotton culture in many parts of the South. This is due to the occurrence, in many of the mountain ranges of the southeastern section of the State, of a wild cotton plant known technically as *Thurberia thespesioides.* This plant, which is so closely related to cotton that some investigators have classed it in the genus Gossypium (the genus of cotton), was found to be the host of a weevil closely related to the cotton-boll weevil, as well as the host of a number of other insects, and it was at once perceived that there was a possibility that these insects might attack cultivated cotton grown near these mountains. Of the various insects found on the wild cotton plant, the weevil is probably the most important, and the present bulletin deals with this species.

HISTORY OF THE WEEVIL.

While the history of the cotton-boll weevil is a familiar subject to almost every one in the infested territory, it is not nearly so well known in the western cotton country, and a brief review of its activities in the United States will help to an understanding of the significance of its presence in Arizona.

The Mexican cotton-boll weevil, *Anthonomus grandis* Boh., came into the United States from Mexico, crossing the Rio Grande at

[1] The investigations on which this paper is based were conducted under the direction of Mr. W. D. Hunter.

Brownsville, Tex., about 1892. Since that time it has advanced steadily northward and eastward until at the present time it is in Texas, Louisiana, Oklahoma, Arkansas, Mississippi, Alabama, and Florida, and the total area infested in 1914 was 312,300 square miles. Estimates made by the Bureau of the Census place the total loss in production of cotton lint in the United States due to the ravages of this species at 10,000,000 bales, or a money loss of $500,000,000. Thus we see the importance of this little beetle of insignificant appearance in the area now infested.

Extended studies have been made by the Department of Agriculture and also by the various State offices in the attempt to reduce the damage done by the species. It has proven one of the most difficult insects to combat, owing largely to its habit of feeding at all times on inner plant tissue and so making the use of poisons practically worthless. The most effective methods of reducing damage which have been developed are principally cultural.

During the summer and fall of 1913 the writer experimented with the Arizona wild cotton weevil and the Texas cotton weevil at Victoria, Tex., crossbreeding them and testing the adaptation of the Arizona form to conditions of cultivated cotton in the South. In April, 1914, the work was transferred to a ranch near Tucson, Ariz., and was continued until the middle of November. This bulletin is a partial result of these studies.

Although the Thurberia plant has been studied botanically for some years, owing to its close relation to cotton, economic interest from an entomological standpoint was first aroused early in 1913, when Mr. O. F. Cook, of the Department of Agriculture, announced the discovery of the weevil breeding in the bolls of this plant in Arizona. This announcement was at once followed by a study of the exact taxonomic status of the weevil, its distribution, habits, and probable economic importance. It was soon found to be not identical with the cotton-boll weevil of the South, but so closely related that the two forms would interbreed readily. It was then described as a variety of *Anthonomus grandis* by Mr. W. Dwight Pierce, of this bureau, and given the varietal name *thurberiæ*. Further investigations lead to the belief that the two types are geographical and environmental varieties arising from a common ancestral form which was probably native to some point in southern or central Mexico. The two forms have probably spread northward along separate lines of distribution in the course of time and have acquired slight differences in structure and habit.

These differences in structure of the adult beetles are so slight that they are not apparent to the untrained eye and the descriptions used in this paper are applicable to either type.

DISTRIBUTION.

The discovery that the weevil breeds on Thurberia furnished the first intimation that it lives on any plant other than those of the genus Gossypium, though the writer has since demonstrated that it is able to develop on some other closely related malvaceous plants. However, it is not likely that this occurs in nature under normal conditions, and there is no reason for believing that the weevil feeds upon any plant other than Thurberia in the mountains. Consequently a study of the distribution and habitat of Thurberia is second in importance only to that of the weevil itself. While our knowledge of this point is by no means complete, considerable information has been gathered in the course of a number of explorational expeditions, and we possess a fair general idea of the conditions.

In Arizona Thurberia is known to occur in the Santa Catalina, Santa Rita, Tanque Verde, Rincon, Mule Pass, Huachuca, Chiricahua, Superstition, Bradshaw, Dos Cabezos, and Dragoon Mountains; at Globe, and in Fish Creek Canyon of the Salt River Valley. In Mexico it has been recorded from Guadalajara, southwestern Chihuahua, and a number of localities in eastern Sonora. The weevils have been found only in the Santa Catalina, Rincon, Santa Rita, Tanque Verde, and Dos Cabezos Mountains. Of these ranges the first four adjoin the Santa Cruz Valley, in which Tucson is located, and the last is near Bowie. From these data it is seen that the plant is rather generally distributed throughout the southeastern part of Arizona and that the weevil infestation, so far as is known at present, is more or less concentrated around Tucson. Of course, additional explorational work will undoubtedly disclose new localities where both plant and weevil are present.

Because of the apparent concentration of the weevils around Tucson it was believed that this was the point of greatest danger of infestation of the cultivated cotton, and the economic investigations were conducted there. While the largest area of cotton cultivation in the State is in the Salt River Valley in the vicinity of Phoenix, the weevil has not been found near there, and the Santa Cruz Valley seemed in more immediate danger.

THE THURBERIA PLANT.

Many of the habits of the weevil are directly dependent upon the characteristics of the Thurberia plant, and the habitat and activities of this plant have been carefully observed. It is found at altitudes ranging from a little over 2,000 feet to 7,000 feet. While colonies are frequently found high on the sides of the canyons and on the ridges, the most common habitat in the mountains around Tucson is in the beds of the canyons and small washes. Here it grows among the

rocks and on the small islands in the bed of the wash wherever there is sufficient moisture and enough protection from the force of the current in flood seasons. (Pl. I, fig. 1.) Many of the small washes down near the base of the mountains, not large enough to deserve the title of canyon, support great numbers of the plants. Following down from such situations the plant is found in the arroyos extending out through the mesa and often at quite a distance from the mountain range proper. (Pl. I, fig. 2.) The economic significance of this lower distribution will be discussed later in the present paper. In the ranges where the weevils have been found their distribution is very nearly as wide as that of the plant.

The Thurberia plant is a large, woody perennial and frequently reaches a height of over 10 feet, though the plants ordinarily met are from 4 to 6 feet tall. (Pl. II.) The stem is very tough after the first year's growth and supports an abundance of wide-spreading branches. The close relationship of the plant to cotton is quite apparent, and particularly so during the flowering period. A great number of buds (corresponding to the "square" of cotton) are produced. After blooming the square forms a small boll not unlike that of cultivated cotton, varying from one-half to three-fourths of an inch in length when fully developed. When these ripen and dry they open and expose the three to five cells, each containing a double row of angular, blackish seeds covered with a fine pubescence. More or less fiber resembling that of cotton is present in nearly every boll. It is in this boll that the weevil breeds.

The flowering season of Thurberia depends upon the location, moisture, altitude, and various other conditions. In practically all localities in the mountains around Tucson the leaves appear in April or May. In the lower, moist spots the plants bear fruit buds almost immediately and many fruit prolifically at this time. After two or three weeks of this flowering the buds cease to appear and there is a quiescent period during which the fruit ripens. Then another crop of buds appears and the same course is repeated. In this manner as many as four crops have been noted on a few plants during the season of 1914 and many bore three. This condition was found only at altitudes below 3,000 feet. Many plants midway up the mountains bore a partial crop in July and then had a heavy one in August and September, while others at much the same altitude had only the latter crop. Throughout the entire upper distribution (above 4,500 feet) the plants grew luxuriantly all summer, but not a single fruiting bud was produced until August. Then an enormous crop appeared, and flowering continued until the latter part of September. This flowering evidently varies in the same situations in the different seasons according to the amount of rainfall.

FIG. 1.—HABITAT OF THE WILD COTTON WEEVIL AND ITS HOST PLANT.

Basin of the Milagroso Canyon in the Santa Catalina Mountains, Ariz. This is an ideal location for *Thurberia thespesioides*, the wild host plant of *Anthonomus grandis* var. *thurberiæ*. Two large plants may be seen near the right-hand margin of the photograph. (Original.)

FIG. 2.—THE WILD COTTON WEEVIL AND ITS HOST PLANT IN THE LOWER RANGES.

Habitat of *Thurberia thespesioides* and the wild cotton weevil in the lower ranges. This view was taken in the Agua Caliente Arroyo, Ariz., about 100 yards below the plant shown in Plate II, figure 1. (Original.)

FIG. 1.—DISPERSION OF THE WILD COTTON WEEVIL.

Typical location of Thurberia plant, below rock, in Agua Caliente Arroyo, Ariz., about 1½ miles from the mouth of the canyon. (Original.)

FIG. 2.—THURBERIA THESPESIOIDES, HOST PLANT OF THE WILD COTTON WEEVIL.

Growth of Thurberia at Agua Caliente Ranch, Ariz., under cultivated conditions. This is one season's growth from seed. (Original.)

INJURY BY BOLL WEEVIL TO SQUARES.

a, Bloom checked by attacks of larva; *b*, square opened, showing grown larva; *c*, square opened, showing pupa; *d*, dwarfed boll opened, showing one larva and two pupæ; *e*, weevil escaping from square; *f*, emergence hole of adult in square. (From Hunter and Pierce.)

INJURY BY BOLL WEEVIL TO BOLLS.

a, Three larvæ in boll; *b*, emergence hole in dry unopened boll; *c*, two larvæ in boll; *d*, weevils puncturing boll; *e*, opened boll, with two locks injured by weevil; *f*, large bolls severely punctured. (From Hunter and Pierce.)

LIFE HISTORY OF THE WEEVIL ON COTTON IN THE SOUTH.

In order to understand the life cycle of the weevil it is well to review briefly its action on cultivated cotton in the Southern States. The female bores a small cavity in the square or boll and deposits the egg in this, sealing the opening with a small gelatinous scale. The egg hatches in a few days and the larva or "worm" feeds upon the inner plant tissue. (Pls. III and IV.) After a period varying from a few days to about two weeks the larva transforms to the pupa, a quiescent stage in which the first resemblance to the adult weevil is shown. After a few days in this stage the pupa sheds its skin and becomes the adult weevil, which quickly leaves the square or boll in which the immature stages were passed and is soon ready to start the cycle again. These immature stages usually require from two to three weeks, although they vary with the temperature, food, and other environmental factors. Starting in May or June and continuing until September or October, as is the case in the cotton States, it is quite possible for six or eight generations to be produced in a single season, and as most females deposit from 100 to 300 eggs or more the progeny of a single pair may reach enormous numbers in the course of a season. In fact, it has been conservatively estimated that the annual progeny of a single pair of hibernated weevils would reach 3,089,520.

LIFE HISTORY OF THE WEEVIL ON THURBERIA.

While the details of the life cycle of the Thurberia weevil in the mountains in Arizona are much the same as those of the cotton weevil in the South, there are a number of important differences. Among them is the mode of hibernation, or manner in which the winter is passed.

Adults of the last fall generation of the cotton weevil usually emerge from the squares or bolls in which they breed and seek shelter in all kinds of situations offering protection near the cotton fields. A great variety of crevices, trash, moss, and other shelters are used for this purpose. The Thurberia weevil, on the other hand, fails to emerge in the fall, but remains sealed up in a cell formed in the midst of the seeds in the boll and passes the winter in this condition. Then in the spring, instead of becoming active with the first warm weather, as the cotton weevil does, the greater number of them remain sealed in the cell until the rains late in the summer, many not emerging until August. This is simply a case of prolonging the period of hibernation into one of aestivation, a habit often observed among species living in arid regions. In order to know when to expect the weevils, a number of experiments have been conducted in the laboratory and close observations have been made in the

field to determine just what conditions are necessary to cause the emergence of the adult. By combining the records secured under both natural and artificial conditions it seems quite possible to determine more or less definitely under what conditions the weevils emerge, and by studying the seasonal climatology of the region inhabited by the weevils we may know when to expect the appearance of the adults.

During the winter the boll containing the weevil cell passes through a continual process of partial disintegration caused by alternate moistening and drying. Following this, more or less moistening of the weevil cell is necessary to allow emergence in most cases, although an occasional individual emerges from time to time from the poorly constructed cells. With this as a basis we need but study the distribution of the rainfall through the spring and summer months in order to determine when emergence of the weevils is to be expected. The temperature is undoubtedly usually high enough by the 1st of April, and the emergence depends almost entirely upon the rainfall from this time onward. April, May, and June are the dry months in this locality, but a study of the seasonal precipitation for a number of years shows that even in the driest of years there are some few light rains in this period and usually some precipitation each month. So we may expect a scattering emergence of the weevil throughout the spring and summer months, the extent of this emergence depending upon the amount of the precipitation, and finally culminating in the almost complete emergence following the heavy rains of July and August.

This very late emergence of the Thurberia weevils shortens the breeding period in the greater part of the mountains to not over two generations annually instead of the six to eight of the cotton weevils.

It should be remembered that while this habit of hibernation and aestivation prevails in nature now, it is by no means certain that it will be adhered to by the weevils in case they attack cultivated cotton in the valley, but it appears likely to continue for some time at least. Weevils reared on cotton in Arizona showed a very definite adherence to this cell hibernation habit when bred in the bolls, but it seems that they will emerge from the squares. Since the females greatly prefer bolls for oviposition it seems probable that nearly all of the late-season breeding will be in these, and consequently little emergence in the fall should be expected. In case the weevil adheres to this cell hibernation habit the control should be quite simple, entailing only the winter destruction of the plants and hibernating weevils.

Most of the breeding on the Thurberia plant seems to be in the bolls, and under normal conditions the bolls from one-third to three-fourths grown are selected for egg deposition. The eggs are placed

in the punctures just as in the case of cotton weevils and the openings are sealed in the usual way. The larva feeds upon the immature seeds and develops in much the same manner and time as the cotton weevil.

DESCRIPTION OF STAGES OF THE WEEVIL.

The egg.—The egg of the weevil is usually elliptical in shape and is of a pearly white color. It is slightly less than 1 millimeter (one twenty-fifth of an inch) in length and is deposited by the female at the bottom of a small opening, usually near the base of the bud or boll, and deep among the plant tissues.

The larva.—Immediately after hatching the young larva is a white legless grub only slightly longer than the egg itself. It feeds entirely upon the inner tissue of the bud or boll and enlarges the cavity as it grows. It soon assumes a ventrally curved, crescentic form and when fully developed averages about 1 centimeter (two-fifths of an inch) in length across the curve.

The pupa.—The pupa is either pearly or creamy white and is very delicate. The form of the legs, beak, and wings may be observed in this stage.

The adult.—When the weevil first transforms from the pupa to the adult it is quite soft, weak, and very light in color. It hardens and darkens in the course of a day or two and is then fully mature. It is a stout, subovate beetle, with a long snout or proboscis. The color varies from light golden brown to very nearly black, according to the age and condition of the individual. When newly emerged it is clothed with light-colored scales, but these frequently rub off in the course of the activities of the weevil, and the darker color of the body predominates.

The size of the adult is also exceedingly variable and is determined largely by the food supply of the larva. In length adults vary from 2.5 to 7 millimeters (one-tenth to one-fourth of an inch).

NATURE OF DAMAGE TO COTTON.

The actual damage of the weevil to cultivated cotton consists in the direct attack upon both the buds and bolls. The adults feed by making punctures with their long beaks deep into the tissues of these, and several such punctures will prevent a bud from blooming or will destroy the lock of the boll in which they are located. By far the greater part of the injury, however, is due to the work of the larval or "worm" stage. The female weevil deposits the egg in the bud or boll and the one larva completely destroys the contents of the bud or lock in which it is located. Within a few days after the deposition of the egg the square "flares." That is, the involucral bracts or greenish leaves, with which the bud is normally

covered, open back flat in a very abnormal position and become pale, sickly yellow. Such an injured square is very conspicuous on a plant in the field and is usually the first indication noted of the presence of weevils. After a few days the square falls to the ground in nearly all varieties of cotton, and in heavily infested fields in the South it is a very common sight to see great numbers of these squares scattered beneath the plants. With the bolls the injury is not so easily noted, since they do not fall unless very heavily infested, but the punctures are readily found by a careful examination, and frequently the form of the boll is distorted. (Pls. III and IV.)

FOOD PREFERENCES OF THE ARIZONA WEEVILS.

A number of tests have been made to determine whether or not the Thurberia weevil displays any preference for either Thurberia or cultivated cotton. These experiments were conducted both in the laboratory and in large cages in the field, and great care was taken to eliminate all factors from the choice other than the actual attraction of the plants. It was found that individuals removed from hibernation cells and offered both plants displayed what seemed to be only the slightest choice in favor of Thurberia, and this disappeared after a few days' feeding. Weevils removed from the cells and fed only upon Thurberia for a few days and then offered a choice at first displayed a marked preference for Thurberia. After a few days' feeding in the presence of both plants this preference gradually disappeared and cotton was as much eaten as Thurberia. Weevils fed only upon cotton for a few days after removal from the cells would at first display a choice in favor of cotton, but this disappeared in the same manner. From these experiments, and also from observations made in the field in 1914, it seems safe to conclude that the weevils have very little inherent preference for either plant and that neither plant has the power to attract them away from the other.

THE TRANSFER TO COTTON.

The transfer of the weevil to cultivated cotton may be accomplished in two ways, i. e., by flight or by water. While it is of course impossible to determine the exact extent of the flight of these weevils, either in distance or frequency, all available evidence seems to indicate that this means is likely to be of little importance in the primary spread of the weevils. It seems that as long as there is an abundance of food at hand the weevils will fly very little, but in case of food shortage they fly readily. On the other hand, the habits and present distribution of the weevil make the species particularly adapted to dispersion by floods. Most of the Thurberia plants grow either directly in the wash of a canyon or arroyo or where the surface drainage is directly into such a wash. Many of the bolls containing

the hibernating weevils in their cells fall to the ground during the months of the winter, spring, and early summer, and because of their size and shape they are well adapted for being carried great distances out through the foothills on to the plains by the floods that occur every season. Here they are deposited by the water, and, the cells having been sufficiently moistened, the weevils emerge. Thence they will fly in search of food, and if they have been carried out into the zone of cotton the danger of infestation is quite apparent. It is in this manner that the infestation is most likely to take place; hence the importance of a study of the surface drainage carrying the water from the infested mountains into the various rivers.

In this connection the distribution of the plants through the lower arroyos is especially important. In many localities these now support weevils and so are a constant menace to cotton, while even where the weevils are not now present they are always likely to serve as stepping stones in the downward movement of the weevil maintained by the floods.

In the course of the investigations several small plats of cotton were planted, comprising in all a little over one-fourth of an acre. On the 30th of July the writer noted several flared squares in this cotton. Examination showed them to contain weevil punctures, and a careful survey of the entire plat revealed the fact that a light infestation of weevils was present. During the remainder of the season all infested squares and bolls noted were collected and a few adult weevils were captured on the cotton. The infestation never became heavy, but it was quite evident that some 10 or 15 weevils arrived at the plat at different times during the next two months. This is of course conclusive proof of the transfer from wild to cultivated cotton.

Early in the season, when a survey of the countryside was made, it was decided that the ranch where this cotton was planted was a logical point for infestation by the boll weevil. It is located at the junction of the arroyos from two large canyons, and consequently receives a concentration of the water flow from these two canyons and all intermediate territory. The Thurberia plant is quite common throughout this drainage system and extends down to within a fourth of a mile of the ranch, although the nearest plants found infested with weevils are slightly farther away. The writer feels that in the course of the weevil collections during the early summer every weevil within at least a mile of the ranch was gathered; the infestation must therefore have been due to weevils brought down by the floods from some distance above. In fact the week before the infestation was first noted there had been a number of rains in this territory, and on one occasion the canyons had poured water down into the washes and out as far as the ranch. These arroyos are nearly

all very rapid in descent near the mountains, and very rocky, so that comparatively little of the water seeps into the ground in this part of the journey and the force of the current scours the channel clean. Just above the ranch the character of the stream bed changes and it becomes wide and sandy. Here the water seeps rapidly and practically every flood of the present season was able to reach but little below the ranch in this sand. Hence the Thurberia bolls containing weevils may be expected to pass through the rapid part of the stream and be deposited on the sand where the flow stops near the ranch. It was probably some such procedure as this which caused the infestation of the experimental cotton during the season of 1914, and the possibility of future infestation will always be present.

PROSPECTS.

From the various observations reported herein it seems quite evident that it is only a matter of time until the weevil will appear on the cotton cultivated near Tucson. The territory best adapted for the cultivation of cotton and that upon which it seems most likely to be raised is nearly all within easy reach of the floods from weevil-infested territory. While it is obviously impossible to state that the infestation will appear at a certain point, there are many places more liable to infestation than others. Such a location has been described at the ranch where the cotton was infested and a number of similar ones occur along the mountain slopes. The fact that the experimental cotton was infested during 1914 demonstrated the importance of such a situation, but, on the other hand, it is by no means certain that the infestation would be repeated each season. However, the movement of the weevils out into the plains which takes place every year must sooner or later result in the infestation of cultivated cotton in the valley. These weevils which are washed into the field can do comparatively little damage themselves, but the result to be feared is that their progeny will become established in the valley, will winter there, and will become more and more adapted to injuring cultivated cotton.

Another point which is likely to be of prime importance in the transfer of the weevil is the practice among many ranchers of using these floods for irrigating their land. A ditch is opened from the arroyo and in time of flood the water is diverted into this ditch and conveyed to the cultivated land. Agua Caliente arroyo is tapped in this manner near one corner of the Agua Caliente ranch and the water is led off to a ranch on the west side of the stream bed. Soldier's Canyon arroyo is tapped in the same way about one-half mile from the mouth of the canyon and the water is carried off to the southwest through several homesteads. The water from Sabino and Bear Canyons is used in the same way near the junction of the two arroyos. Since these

ditches all leave the washes at points very close to Thurberia plants and in some cases among weevil-infested plants, it is quite easy to see the probable importance of this method of irrigation in introducing weevils and weevil-infested bolls directly into the fields.

It is also the custom of a number of ranchers down in the river valleys to allow their land to be flooded whenever possible in order to secure the soil deposit as well as moisture. While these places are farther from weevil sources it is quite possible for weevils to be introduced in this manner.

At present the cotton cultivated near Tucson is practically all northwest of the city near the Santa Cruz and Rillito Rivers. The nearest mountains in which we have found the weevils are the Santa Catalinas, and at the western end these drain more or less directly into the valley now cultivated. Pima Canyon and the small washes adjoining it drain slightly west of south into the Rillito and thence directly into cotton land. The northwestern slope at this end of the range, including Montrose and Romero Canyons, drains into the Canada del Oro, and this water flows southwest into very nearly the same territory. The drainage of the entire southern slope of the Catalina Range is thickly infested with the weevils, which frequently extend along the "washes" very nearly to the Rillito. There is no doubt that every season a number of weevils are washed down into this country, and any cotton cultivated in this part of the Rillito Valley will be in constant danger of infestation. On the east the Tanque Verde Mountains supply a stock of weevils carried down toward the village of Tanque Verde, while southeast of Tucson, near Vail and Irene, the headwaters of the Pantano are furnished with weevils from the ends of the Rincon and Santa Rita Ranges. South of Tucson in the valley of the Santa Cruz the drainage from the northwestern slopes of the Santa Ritas contains weevils and Thurberia plants well down toward the river itself. West of Tucson there seems to be very little danger other than that from the end of the Catalinas, as the Tucson and other ranges here seem unable to support the plant.

Under the existing circumstances there seems to be no measure which can be taken to prevent the introduction of the weevil into cotton fields, but a close watch should be continued at all times in order that an attempt may be made to control them as soon as they appear. Planters should maintain a careful watch for either flared or fallen squares and bolls in the field and examine them for either the feeding punctures or larvæ of the weevils. This observation should be especially close in fields or parts of fields adjacent to water courses carrying drainage from situations such as those described as normal for Thurberia.

At the present stage of the investigations it is impossible to predict just what the extent of the damage by the weevils will be when

they attack cotton. Many of the habits of the Thurberia weevil are adapted to the activities of these plants and to the higher altitudes at which they live, and it is questionable just how readily and to what extent it will adapt itself to cotton. But since the species has shown such great adaptiveness in the Southern States, it is to be feared that the Arizona form will do the same. At any rate, it is an ever-present menace to cotton cultivation in the Santa Cruz Valley and should be watched most carefully. It is quite probable that with a more intimate knowledge of the extent of the weevil distribution in the State it will be possible to establish local quarantines of seed-cotton shipments which will at least keep the weevils out of the localities which do not have the species present in nature. In the Southern States cotton cultivation is of course very general and there the weevil advances each season by flying, but in Arizona, where the different areas suitable for cultivation are separated by considerable stretches of mountainous country, such a means of dispersion would only be possible within very limited areas. Consequently it should be possible to keep the weevil entirely out of areas not within range of direct infestation from nature.

In addition to the watch for infestation by native weevils, the danger of importation of the weevil from the Southern States should be remembered, and all efforts should be made to validate the quarantine against this variety.

SUMMARY.

1. A weevil very closely related to the Mexican cotton-boll weevil exists on a wild cotton plant in some of the mountains of southeastern Arizona.

2. The species seems to be particularly concentrated in the ranges surrounding Tucson.

3. This weevil may transfer its attack from the wild cotton plant to the cultivated cotton in the Santa Cruz and Rillito Valleys at an early date.

4. Its present habits are such that it would not injure cotton greatly, but these habits will probably be changed to a certain extent and more injurious ones acquired.

5. The present habits render it quite probable that the control of the Arizona form will be a very different problem from that of the cotton weevil and more easily solved.

6. A careful watch should be maintained for the first appearance of the weevil on cultivated cotton in order that it may be combated successfully.

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PROFESSIONAL PAPER.

UTILIZATION AND MANAGEMENT OF LODGEPOLE PINE IN THE ROCKY MOUNTAINS.

By D. T. Mason, *Assistant District Forester, District 1.*

CONTENTS.

OWNERSHIP AND SUPPLY.

Lodgepole pine (*Pinus contorta*) is the most important timber tree of that portion of the Rocky Mountains lying between northern Colorado and central Montana. Once considered practically worthless, it now brings the Federal Government a revenue of from $10 to $100 an acre in National Forest timber sales.

By far the greater part of the present supply of lodgepole pine is included within the National Forests. As will be seen from Table 1, it is the most important tree species on a number of Forests in Montana, Wyoming, Colorado, Idaho, and Utah, forming in such cases from 30 to 92 per cent of the total stand of timber, and is of commercial though not primary importance on still other Forests in these States and in Washington, Oregon, and California. The principal privately owned bodies of lodgepole pine of any size are in Montana, where the State and the Northern Pacific Railroad hold considerable tracts. The total stand of lodgepole pine on those Forests where it is commercially important has been estimated at about 40 billion board feet (Table 1). Figure 1 shows by National Forests the regions where lodgepole pine occurs, either commercially or botanically.

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TABLE 1.—*Estimated stand of lodgepole pine on the National Forests in which it is of commercial importance.*

State.	Stand of lodgepole pine, 1,000 board feet.	Per cent of total stand.
MONTANA.		
Forests in which lodgepole pine is most important species:		
Missoula	2,464,000	80
Beaverhead	1,132,000	75
Gallatin	750,000	75
Jefferson	88,000	75
Deerlodge	666,000	68
Madison	527,000	60
Absaroka	819,000	60
Beartooth	203,000	41
Helena	440,000	40
Lewis and Clark	750,000	30
Forests in which lodgepole pine is of commercial but not of primary importance:		
Bitterroot	1,713,000	46
Blackfeet	225,000	10
Flathead	819,000	13
Lolo	118,000	7
Kootenai	600,000	5
Total	11,314,000	
WYOMING.		
Forests in which lodgepole pine is most important species:		
Medicine Bow	2,392,000	92
Washakie	255,000	85
Bighorn	895,000	80
Hayden	480,000	80
Bridger	432,000	70
Bonneville	426,000	60
Wyoming	408,000	40
Shoshone	396,000	24
Total	5,684,000	
COLORADO.		
Forests in which lodgepole pine is most important species:		
Arapaho	1,517,000	65
Colorado	753,000	61
Forests in which lodgepole pine is of commercial but not of primary importance:		
Holy Cross	260,000	40
Leadville	385,000	34
Routt	417,000	25
Gunnison	88,000	18
Sopris	73,000	10
Pike	86,000	8
White River	55,000	5
Cochetopa	12,000	3
San Isabel	17,000	2
Total	3,663,000	
IDAHO.		
Forests in which lodgepole pine is most important species:		
Idaho	2,210,000	85
Targhee	420,000	50
Palisade	112,000	32
IDAHO—continued.		
Forests in which lodgepole pine is of commercial but not of primary importance:		
Challis	370,000	37
Caribou	24,000	35
Nez Perce	875,000	25
Selway	1,818,000	25
Minidoka	58,000	20
Sawtooth	146,000	20
Boise	371,000	11
Weiser	146,000	11
Salmon	100,000	5
Payette	153,000	3
Clearwater	120,000	2
Coeur d'Alene	10,000	0.3
Total	6,933,000	
UTAH.		
Forests in which lodgepole pine is most important species:		
Ashley	1,446,000	65
Uinta	732,000	60
Forest in which lodgepole pine is of commercial but not of primary importance:		
Cache	6,000	5
Total	2,184,000	
WASHINGTON.		
Forests in which lodgepole pine is of commercial but not of primary importance:		
Wenaha	2,080,000	40
Okanogan	900,000	15
Chelan	277,000	12
Kaniksu	67,000	5
Wenatchee	41,000	1
Total	3,365,000	
OREGON.		
Forests in which lodgepole pine is of commercial but not of primary importance:		
Paulina	2,456,000	50
Minam	799,000	33
Deschutes	798,000	19
Whitman	440,000	10
Wallowa	251,000	6
Umatilla	45,000	3
Fremont	132,000	2
Malheur	105,000	1.6
Ochoco	118,000	1.3
Total	5,144,000	
CALIFORNIA.		
Forests in which lodgepole pine is of commercial but not of primary importance:		
Lassen	1,200,000	10
Sequoia	469,000	7
Kern	309,000	5
Mono	105,000	30
Total	2,083,000	

Total stand of lodgepole pine on those National Forests where it is of commercial importance, 40,380,000,000 board feet.

CHARACTERISTICS OF THE WOOD.

The wood of lodgepole pine is straight grained, with narrow rings in which the resinous bands of summerwood are conspicuous, though relatively small when compared with the springwood. It is more resinous than eastern white pine (*Pinus strobus*), but less so than the yellow pines of the South and West. In color it varies from almost white to a light yellow or yellow-brown, with a tinge of red in the heartwood. Its specific gravity (oven dry) is about 0.38, and its weight varies from 25 to 30 pounds per cubic foot. The wood is fairly soft—about the same as eastern white spruce (*Picea canadensis*)—and is easily worked. Though not so strong as Douglas fir of the Pacific coast (*Pseudotsuga taxifolia*), a heavier wood, tests made by the Forest Service show it to be practically as strong as western yellow pine (*Pinus ponderosa*), and stronger than Engelmann spruce (*Picea engelmanni*) and Alpine fir (*Abies lasiocarpa*), three woods of more nearly its weight. Tests made on lodgepole pine and western red cedar (*Thuja plicata*) telephone poles cut green and seasoned showed lodgepole pine to be the stronger, both in crossbending and in compression parallel and perpendicular to the grain. The strength of fire-killed lodgepole-pine poles was found to be approximately the same as that of red cedar poles cut green and seasoned. Lodgepole pine is not durable in contact with the soil, but is easy to treat with preservatives. Plate I shows magnified sections of the wood. Table 2 gives figures of strength for green and air-seasoned lodgepole pine compared with figures for other Rocky Mountain woods.

TABLE 2.—*Strength of green*[1] *and air-seasoned*[1] *lodgepole-pine timber, compared with other Rocky Mountain species.*

[Based on tests of small, clear specimens, 2 by 2 inches in cross section, with a 28-inch span in the bending test.]

Species and locality.	Rings per inch.	Specific gravity.[1]	Moisture content.	Static bending.			Compression parallel to grain (crushing strength).	Compression perpendicular to grain (fiber stress at elastic limit).
				Modulus of rupture.	Modulus of elasticity.	Work to maximum load.		
			Per cent.	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*Inch-lbs. per cu. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Lodgepole pine, Grand County, Colo.	21	0.370	44	5,130	1,015	5.1	2,530	364
	......	.392	11.0	8,740	1,270	6.7	5,520	779
Lodgepole pine, Johnson County, Wyo.	30	.371	58	5,170	972	5.3	2,400	332
	......	.390	12.0	8,750	1,176	5.2	5,330	824
Douglas fir, Johnson County, Wyo.	17	.418	32	6,340	1,242	7.0	2,920	427
	......	.435	12.0	9,320	1,392	6.3	6,050	744
Western yellow pine, Coconino County, Ariz.	21	.353	98	4,760	879	4.9	2,220	342
	......	.384	11.6	8,150	1,103	4.6	5,220	790
Western yellow pine, Douglas County, Colo.	32	.391	93	5,460	1,053	6.0	2,600	410
	......	.411	13.8	9,400	1,263	7.0	4,920	714
Western yellow pine, Missoula County, Mont.	18	.371	119	4,950	865	5.2	2,370	313
	......	......	......	......	......	......	......	......
Engelmann spruce, Grand County, Colo.	17	.325	45	4,550	866	4.8	2,170	302
	......	.342	12.8	7,740	1,074	5.4	4,560	589
Engelmann spruce, San Miguel County, Colo.	11	.299	156	3,850	798	5.0	1,800	279
	......	.314	16.8	5,860	990	5.4	3,060	447
Alpine fir, Grand County, Colo.	15	.306	47	4,450	861	4.4	2,060	307
	......	.321	15.9	5,960	887	3.4	3,400	504

[1] Based on oven-dry weight and volume when tested for strength.

NOTE.—Values for green timber on first line, for air-dry on second line, opposite species and locality.

USES.

MINE TIMBERS AND CONVERTER POLES.

In Montana lodgepole pine is used mainly for mine timbers. Butte offers the greatest single market for the wood to be found anywhere, consuming annually about 250,000 lodgepole-pine stulls, scaling some 10,000,000 board feet, and 130,000 lagging poles. The stulls vary in length from 14 to 16 feet, and in diameter from 6 to 23 inches. The lagging poles are 16 feet long, with a diameter of only 3 or 4 inches.

Butte consumes annually about 95,000,000 board feet of timber of all kinds, of which nearly 90 per cent is sawed yellow pine, fir, and larch (*Larix occidentalis*), the remainder being made up largely of the round lodgepole-pine timbers mentioned in the preceding paragraph. Wherever practicable mine operators are now replacing the sawed timber with lodgepole-pine timber in the round for the sake of economy. Sawed timber at Butte costs approximately $18 per thousand board feet, while an equivalent amount of lodgepole pine, from the standpoint of strength, can be delivered there for $8.50. Round lodgepole-pine timber, moreover, is "framed" by machinery, while the sawed timber must usually be framed by hand, a more expensive process.

In addition to the metal mines, the coal mines of Montana, Wyoming, and Colorado consume large quantities of lodgepole pine in the round, and this market is steadily growing. Still another market is offered by the smelters at Anaconda and Great Falls, which use annually about 50,000 converter poles, from 24 to 30 feet long and from 3 to 5 inches in diameter, in the final process of deoxidizing the matte.

RAILWAY TIES.

Lodgepole pine has been used for crossties ever since the first transcontinental railroad was built across the Rocky Mountains. Its short life in service under natural conditions, however, does not recommend it to the railroads as a tie material unless it can be treated with preservatives. At present lodgepole pine is not much used for ties in Montana, because the treating plants maintained by the Great Northern and Northern Pacific Railroads are both located in the western part of the State, where large quantities of Douglas fir and larch are available. As the supply of these woods is reduced, however, it is likely that lodgepole pine will find a much wider use in Montana as a tie material.

In Wyoming lodgepole pine is used in considerable quantities for crossties, two of the transcontinental railroads maintaining large treating plants at Laramie and Sheridan, respectively, at the first

of which lodgepole pine is the only wood treated and at the other forms the bulk of the material handled. Both plants use zinc chloride as the preservative, injecting a solution into the timber under pressure. Census figures show that in 1911 92,158 ties were treated by this process in Wyoming. One of the railroads estimates the life of a treated lodgepole-pine tie at 10 years, as compared with 5 years when untreated.

The wood is not used for ties to any extent in Colorado, and the material employed is untreated.

LUMBER.

Lodgepole pine finds a relatively small use as lumber, forming only 0.1 per cent of the total lumber cut of the United States. Even in mature stands only about 20 per cent of the material is large enough for saw timber, and the logs taken out run from 20 to 30 to the thousand board feet. Such sizes do not yield wide lumber, and are more expensive to log than larger stuff. The mills in the lodgepole region, moreover, are as a rule not equipped to turn out a high-grade product. Yet, when carefully manufactured, lodgepole pine lumber is by no means as inferior as many persons seem to believe. In quality it ranks between western yellow pine and western white pine (*Pinus monticola*), and in fact, is usually mixed with the former, and sometimes with the latter. While the small sound knots which are characteristic of lodgepole pine make it difficult to turn out any large quantity of clear lumber, they do not prevent a high percentage from going into No. 1 and No. 2 common of the narrower widths. At present most of the lodgepole pine lumber is used locally for rough construction and repairs, though in some places where other species are not available it is also used for flooring, siding, and finish.

Table 3, which is based upon figures gathered by the census, shows that the use of lodgepole pine for lumber, though restricted, is steadily increasing. As a matter of fact, the annual increase in the lumber cut is probably even greater than the table indicates, since the figures for 1909 are based on reports from a larger number of mills, and so more nearly represent the total cut for the year than those for 1910 and 1911. It is also probable that the cut of lodgepole pine in the "Inland Empire" (northwestern Montana, northern Idaho, and eastern Washington) is larger than that shown, due to the fact that many mills in the region market lodgepole pine with lumber of other species under the name of the latter, and report it as such.

TABLE 3.—*Annual cut of lodgepole pine for lumber, 1909–1911.*

State.	1909	1910		1911	
	Annual cut.	Annual cut.	Increase over previous year.	Annual cut.	Increase over previous year.
	Board feet.	*Board feet.*	*Per cent.*	*Board feet.*	*Per cent.*
Wyoming	11,886,000	13,205,000	11.1	13,294,000	0.7
Colorado	6,730,000	9,572,000	43.7	15,038,000	57.1
Montana	2,567,000	2,308,000	[1] 7.3	3,348,000	40.7
Idaho	1,228,000	934,000	[1] 23.9	779,000	[1] 14.5
All other States	1,322,000	543,000	[1] 58.9	535,000	[1] 1.5
Total	23,733,000	26,634,000	12.2	33,014,000	24.0

[1] Decrease.

POSTS AND POLES.

Large quantities of lodgepole pine are cut for fence posts and rails for local use, but at present the species is not generally employed for telegraph, telephone, or power line poles. Lodgepole pine, however, is in many respects an excellent pole timber. It is straight, with a taper of approximately 1 inch in 8 feet, about the same as that of western red cedar, and when air dried is 19 per cent stronger at the elastic limit and 12 per cent stronger under maximum load than a cedar pole of the same circumference at the ground line. The poles must, of course, be given a preservative treatment if they are to last any length of time. Poles treated with creosote by the open-tank process are estimated to have a life of 20 years or more, against 5 years when untreated. Even treated lodgepole, however, would be a cheaper pole material than untreated western red cedar in central and eastern Montana and in many portions of the region between the Rocky Mountains and the Mississippi River, owing to its lower stumpage value and greater accessibility. Table 4 shows the cost of treated lodgepole pine, in contrast with that of untreated cedar, for a telephone line near Butte.

TABLE 4.—*Comparative cost of treated lodgepole pine and untreated western red cedar telephone poles near Butte, Mont.*

	Treated lodgepole.[1]	Untreated cedar.
Cost per 7-inch, 25-foot pole, f. o. b. Butte	$0.75	$2.25
Cost of treatment	.60	
Cost of hauling and setting	5.00	5.00
Total cost in place	6.33	7.25
Life in service	[2]22 yrs.	10 yrs.
Annual charge[3]	$0.527	$0.985
Annual saving per pole by using lodgepole pine	.458	

[1] Treated with 4 pounds of creosote per cubic foot; penetration of 1.29 inches.
[2] Estimated.
[3] Calculated by the formula—

$$r=\frac{R\times 1.0p^n\times .0p}{1.0p^n-1}$$

where r=equivalent annual charge; R=initial expenditure; $.0p$=rate of interest; n=term of years.

Two factors operate against lodgepole pine as a substitute for cedar poles. The first is its greater hardness, which makes climbing more difficult for the lineman; the second is its greater weight—approximately 30 per cent after 3 months' seasoning—which means a higher freight rate for poles of the same size. Lodgepole pine, however, grows much farther east than cedar, and so should really have the advantage in freight rate for a considerable distance into middle western markets. Treated lodgepole pine poles, furthermore, do not need to be as large in circumference at the ground as cedar poles, for the latter must be large enough in the first place to bear the load after the sapwood and part of the heartwood have decayed. For this reason the shipping weight of treated lodgepole pine poles should be close to that of cedar when the same strength is required.

From present indications it seems likely that lodgepole pine will to a large extent replace cedar as a pole material in many parts of the West within the next few years.

PAPER PULP.

Lodgepole pine yields a ground-wood pulp of good quality, suitable for the manufacture of news-print paper. It can also be made into pulp by the sulphite process.

The National Forests contain many large bodies of lodgepole pine timber conveniently located with reference to undeveloped water power. No doubt the manufacturer of news-print paper will stick to white spruce for his raw material as long as any can be obtained either in this country or in Canada, but the lodgepole pine of the National Forests offers an immediate opening to manufacturers of other ground-wood products who have not an abundance of raw material and cheap power at their present locations. The rapid growth of the pulp-board industry during the last few years, for example, has created a demand for a suitable and inexpensive wood which lodgepole could well supply.

FUEL AND CHARCOAL.

A considerable amount of lodgepole pine is used locally for fuel. At one time large quantities were made into charcoal, but the industry has fallen away since the introduction of coke. From 15,000 to 20,000 bushels are still produced annually, however, in the vicinity of Bernice, Mont.

FIRE-KILLED TIMBER.

Lodgepole-pine timber killed by either fire or insects deteriorates very slowly as long as it remains standing. Dead trees may stand for 20 or 30 years, and even after falling to the ground will not decay quickly unless in direct contact with the soil. Finally, however, the interior of the stem gives way to red rot, leaving the sapwood as a

hard shell on the outside. The principal damage to standing dead timber comes from checking, which impairs its value for saw purposes, but not for mine timbers and poles. In one stand of lodgepole pine on the Beartooth National Forest, Mont., where the timber was killed by fire in 1893, a sawmill is now at work cutting rough lumber for local use.

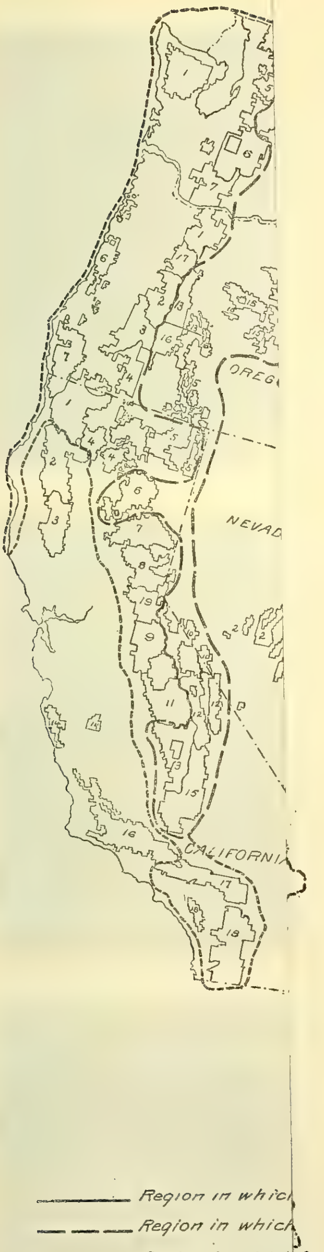
SIZE AND CONTENTS OF VARIOUS PRODUCTS.

Table 5 gives the sizes of the various lodgepole-pine products and the contents of the average pieces of each class in cubic feet and board feet. Material under 6 inches in diameter has been converted from cubic feet to board feet by using the factor 4.

TABLE 5.—*Sizes and contents of various products of lodgepole pine.*

Product.	Dimensions.	Cubic feet equivalent.[1]	Board feet equivalent.	Number of pieces per 1,000 board feet.
Fuel	4′ x 4′ x 8′	82.42	330	3
Ties (pole ties)	7″ to 8″, 8″ to 10″ face, 8′ long[2]	6	30	33
Telephone poles	5″ to 6″ x 22″[3]	5.9	24	42
Derrick poles	7″ x 30′	15	60	17
Converter poles	3″ to 4″ x 24′	3	12	83
Fence poles	2½″ x 16′	1	4	250
Fence posts, round	5″ to 6″ x 7′	1.4	6	167
Fence stays	2″ x 6′	.21	.5	2,000
Do	4″ x 6′	.67	2	500
Lagging, round	2½″ x 16′	1	4	250
Mine props	5″ x 14′	2.7	11	91
Round material, cubic feet, average log	6″ to 16′	4.3	20	50
Do	8″ to 16′	7.1	30	33
Do	16″ to 16′	25.2	160	6
Round material, linear feet	6″ x 1′			
Do	8″ x 1′			
Do	10″ x 1′	.545	2.5	400
Do	12″ x 1′	.785	3.5	286

[1] Cubic foot equivalent is taken from Table I, Graves's Forest Mensuration, p. 107.
[2] These are Union Pacific specifications, but they are not always rigidly enforced. Ties fulfilling specifications would scale about 37 board feet each. Actual scale of ties in several places shows average contents to vary from 22.5 to 37 board feet. An average of 30 board feet per tie for the region is reasonable.
[3] This size used locally by ranchers.



IDAHO:
1. Boise.
2. Pend Oreille.
3. Coeur d'Alene.
4. Clearwater.
5. Nezperce.
6. Idaho.
7. Wieser.
8. Payette.
9. Kaniksu.
10. Minidoka.
11. Pocatello.
12. Cache.
13. Caribou.
14. Palisade.
15. Salmon.
16. Lemhi.
17. Challis.
18. Sawtooth.
19. St. Joe.
20. Selway.
21. Targhee.

MONTANA:
1. Kootenai.
2. Sioux.
3. Lewis and Clark.
4. Flathead.
5. Cabinet.
6. Lolo.
7. Bitterroot.
8. Missoula.
9. Deerlodge.
10. Beaverhead.
11. Madison.
12. Gallatin.
13. Helena.
14. Jefferson.
15. Absaroka.
16. Beartooth.
17. Custer.
18. Blackfeet.

ARKANSAS:
1. Ozark.
2. Arkansas.

KANSAS:
1. Kansas.

WYOMING:
1. Sundance.
2. Shoshone.
3. Bridger.
4. Teton.
6. Wyoming.
7. Bighorn.
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5. Apache.
6. Crook.
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8. Chiricahua.
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11. Prescott.
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UTAH:
1. La Sal.
2. Ashley.
3. Uinta.
4. Wasatch.
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16. Pike.
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18. Durango.

NEW MEXICO:
1. Jemez.
2. Zuni.
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4. Pecos.
5. Manzano.
6. Lincoln.
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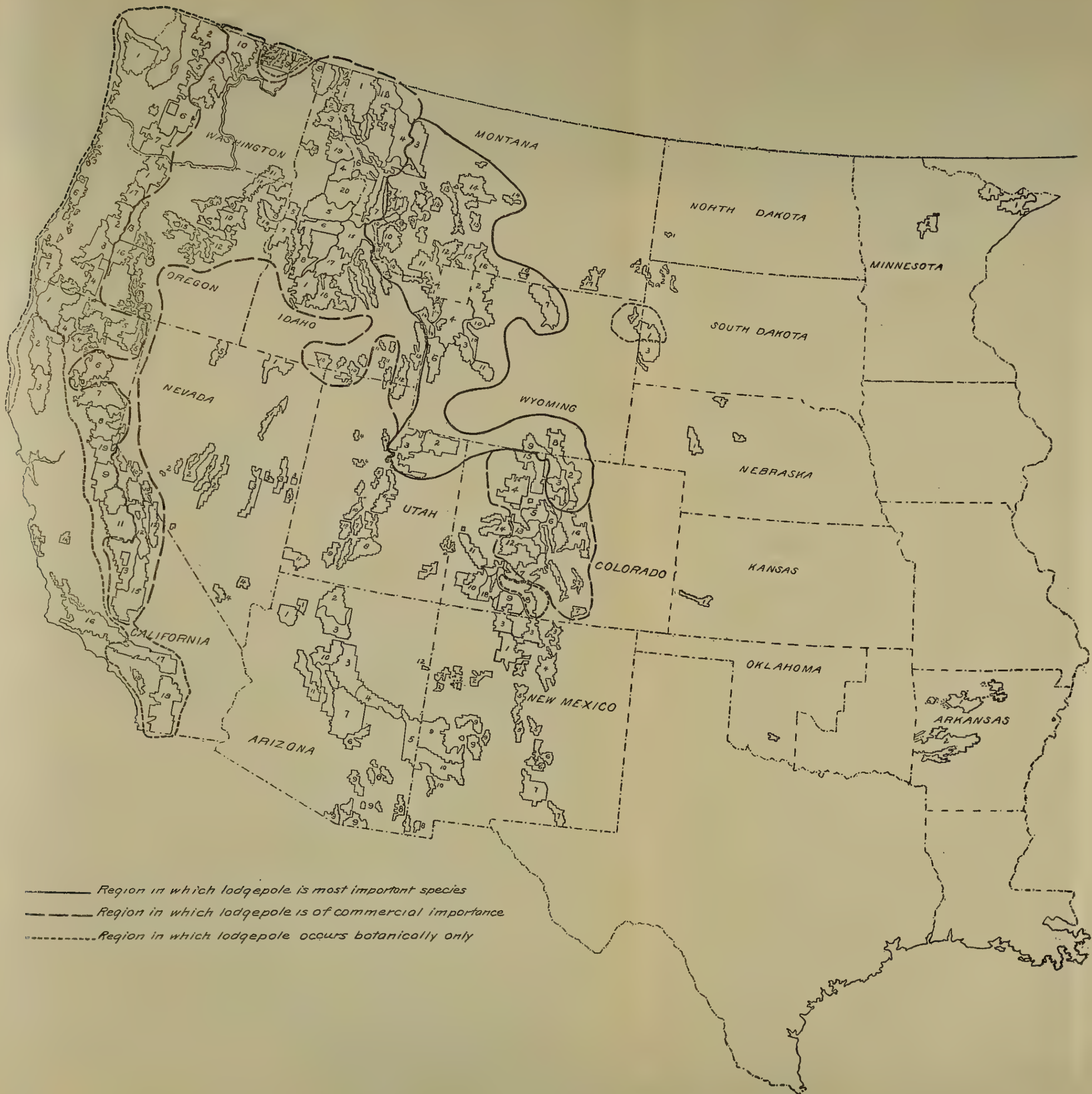

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FIG. 1—Occurrence of Lodgepole pine in National Forests.

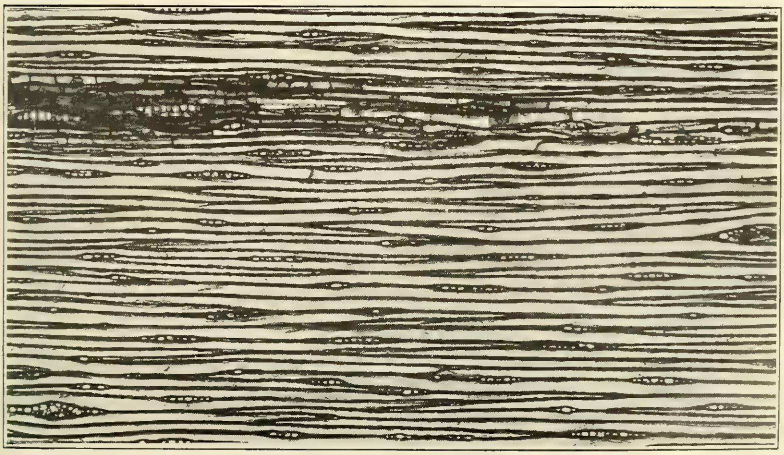

Fig. 1.—Tangential Section.

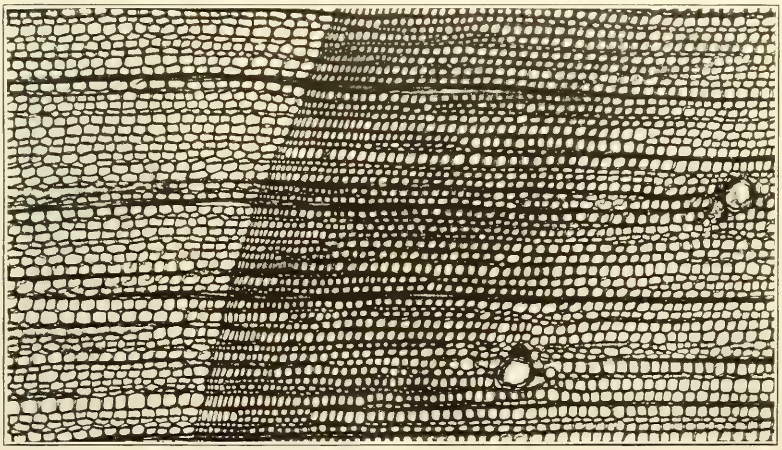

Fig. 2.—Transverse Section.

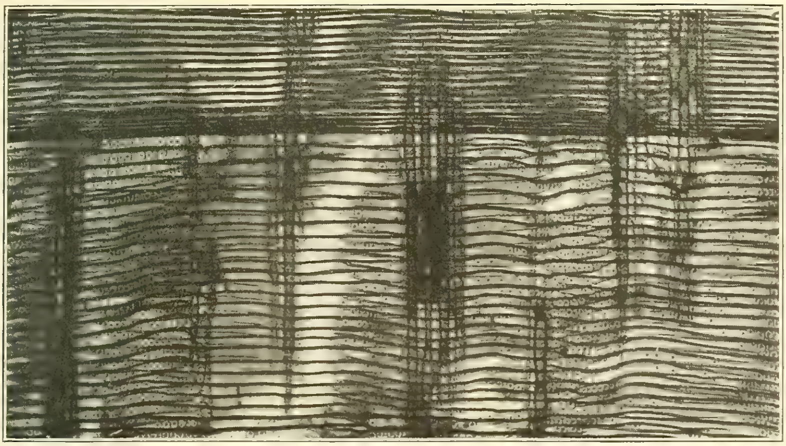

Fig. 3.—Radial Section.

LODGEPOLE-PINE WOOD MAGNIFIED 50 DIAMETERS.

FIG. 1.—CHUTE DOWN WHICH LODGEPOLE-PINE STULLS AND OTHER MATERIAL ARE BROUGHT TO RESERVOIR IN FOREGROUND, DEERLODGE NATIONAL FOREST.

FIG. 2.—FLUME FOR TRANSPORTING LODGEPOLE-PINE TIES, PROPS, AND SLABBED LOGS, BIGHORN NATIONAL FOREST.

Table 6 shows the contents in cubic feet and board feet of stulls of various sizes.

TABLE 6.—*Contents of stulls of various sizes, Deerlodge National Forest, Mont.*

Size.		Contents.		Number of pieces per thousand board feet.	Number of board feet per cubic foot.	Weight per piece (20 per cent moist 33.1 lbs. per cubic foot).[2]
Length.	Top diameter inside of bark.					
Feet.	*Inches.*	*Cu. ft.*	*Bd. ft.*[1]			*Pounds.*
14	5	2.7	5	200	1.8	89
	6	3.6	10	100	2.8	119
	7	4.5	20	50	4.4	149
	8	6.0	20	50	3.3	199
	9	7.6	30	33	4.0	252
	10	9.4	40	25	4.3	311
	11	11.4	50	20	4.4	377
	12	13.4	70	14	5.2	444
	13	15.6	80	12	5.1	516
	14	17.9	100	10	5.6	592
	15	20.3	120	8	5.9	665
	16	22.8	140	7	6.1	755
	17	25.7	160	6	6.2	851
	18	28.6	190	5	6.6	946
16	6	4.4	20	50	4.5	145
	7	5.8	30	33	5.2	192
	8	7.4	30	33	4.1	245
	9	9.2	40	25	4.3	304
	10	11.3	60	17	5.3	374
	11	13.5	70	14	5.2	447
	12	15.9	80	12	5.0	526
	13	18.3	100	10	5.5	606
	14	20.9	110	9	5.5	692
	15	23.6	140	7	5.9	781
	16	26.6	160	6	6.0	880
	17	29.9	180	5	6.0	990
	18	33.6	210	5	6.3	1,112

[1] Rounded off to even tens by the Scribner Decimal C rule.
[2] This is calculated for a uniform moisture content of 20 per cent, with a weight of 33.1 pounds per cubic foot. As a matter of fact, the moisture content at the time of shipment varies considerably—from 15 per cent to 60 per cent.

ANNUAL CUT.

The annual cut of lodgepole pine by States, as nearly as it can be determined, is shown in Table 7. This table indicates a considerably smaller cut of saw timber than Table 3, due to the fact that some mills which formerly sawed lodgepole pine have shut down, and to the further fact that some of the material included in Table 3 as saw timber appears in Table 7 as ties and mine timbers.

TABLE 7.—*Approximate total cut of lodgepole pine by States for year ending June 30, 1913.*

[The figures include the cut from private as well as from National Forest lands.]

State.	Total cut of lodgepole pine.	Mine timbers.	Saw timber.	Cordwood.	Railroad ties.	Fencing.	Miscellaneous.
	1,000 bd. ft.	*1,000 bd. ft.*	*1,000 bd. ft.*	*1,000 bd. ft.*	*1,000 bd. ft.*	*1,000 bd. ft.*	*1,000 bd. ft.*
Montana	30,497	14,632	2,805	8,554	108	4,083	315
Colorado	15,680	4,737	5,881	387	4,483	125	67
Wyoming	14,523	3,236	7,646	1,246	1,622	697	76
Utah	10,753	1,955	1,808	90	6,842	58	....
Idaho	6,880	167	1,273	2,624	494	1,349	973
Oregon	1,916	43	64	1,048	222	498	41
Washington	1,765	....	....	1,582	....	182	1
California	236	....	86	120	....	....	30
Total	82,250	24,770	19,563	15,651	13,771	6,992	1,503
Total cut from private lands	18,725	3,804	4,815	304	9,662	115	25
Per cent from private lands	22.8	15.4	24.6	1.9	70.2	1.6	1.7

METHODS OF LUMBERING.

Lodgepole-pine stands are logged with horses, steam logging being impracticable because of the small size of the timber and the small stand per acre. The ordinary lumbering operation may be divided into four parts: (1) Felling the trees and cutting them into logs, ties, mine timbers, and other products; (2) skidding the material to hauling roads and hauling on wagons or sleds to a flume, river, chute, or railroad, and, in some cases, direct to the mill; (3) fluming, driving, or railroading the material to the mill or market; and (4) milling. Cutting and skidding are done mainly in the summer and fall and driving and fluming in the spring. Railroad hauling may of course be carried on at any season. The exact methods adopted for each part of the lumbering operation differ with local conditions and the class of material handled.

FELLING AND CUTTING.

Saw logs are cut in the usual manner by a two-man crew that fells the tree, trims the branches, and cuts the stem into log lengths. In average timber such a crew will cut from 4,500 to 5,000 board feet, log scale, per day.

Tie trees—that is, trees from 11 to 15 inches in diameter, breast-high—are felled and hewed into ties by one man, who uses a single crosscut saw for felling and a broadax for hewing. The trees are marked into 8-foot lengths and hewed along two parallel faces to the proper dimensions. The bark is then peeled from the upper side, and the portion of the tree suitable for ties is cut up into the proper lengths. If the tree is a large one the tie cutter ordinarily cuts one saw log from the butt, while the top portion is left in the round and utilized for mine timbers. On the basis of figures for 15 trees, averaging 12.1

inches in diameter, with three ties to a tree, a tie maker produces about 21.5 ties in 8 hours' work with a distribution of time per tie as follows:

	Time per tie.	Per cent of total.		Time per tie.	Per cent of total.
	Minutes.			*Minutes.*	
Felling	1.6	7.2	Time lost between trees	1.2	5.4
Trimming and making	1.1	4.9	Sharpening tools	1.2	5.4
Scoring	3.4	15.2	Strip road building	1.0	4.5
Hewing	4.2	18.8	Parking ties	2.5	11.7
Peeling (top side)	1.2	5.4			
Sawing	2.6	11.7	Total	22.3	100
Peeling (underside)	2.2	9.8			

Often he cuts the saw-log trees, or at least the smaller ones, as well as the tie trees. In tie operations it is the usual practice to lay out the timber in parallel strips from 100 to 150 feet wide, each of which is assigned to a tie cutter. A road is then cut through the middle of each strip or, if the topography does not permit this, between every two strips. The choppers usually dispose of the brush, although this may be done by a separate crew.

In a typical tie operation on the Uinta National Forest, in Utah, the specifications provided for ties 8 feet long, from 7 to 8 inches thick, with from 8 to 10 inches face. Seven-inch faces were allowed in not to exceed 20 per cent of the first-class ties. Cull ties were required to have a minimum face of 6 inches, but had to meet the other specifications as to length and thickness. The stand in which the cutting was done averaged slightly less than 12,000 board feet per acre, with 72 per cent suitable for hewed ties, 18.5 per cent for saw logs, and 9.5 per cent for mine timbers. From 126 to 460 ties, or an average of 228, were secured per acre. The "tie hacks" were required to construct the roads through the middle of the 100-foot strips and also to park the ties along these roads, but were not required to dispose of the brush. They were paid 14 cents for first-class and 7 cents for cull ties, but were not paid for rejects. At the final inspection the product of the cutting was shown to be 97 per cent first-class ties, 2.5 per cent culls, and 0.5 per cent rejects. Thus the average price paid to the cutters per tie amounted to 13.7 cents. The cutters received $1.50 per thousand board feet for saw logs over 13 inches in diameter, though ordinarily the portion of the tree over 13 inches was made into ties like the rest. The ties, which were unusually large, showed an average scale of 37 board feet each, or 27 pieces to the thousand board feet. At a treating plant at Laramie, Wyo., 150 ties gave an average scale of 28.2 board feet each, or 35.5 pieces per thousand board feet. Some 2,000 ties scaled on the Bighorn National Forest, in Wyoming, averaged 26 board feet per tie, and an equal number on the Arapahoe Forest, Colo., averaged 22.5 board feet.

Where the cutting is mainly for mine timbers, as is the case in most parts of Montana, the various classes of material are produced in the woods by small groups of choppers at contract prices. Each group, usually called a "company," consists of from 2 to 5 men, and is assigned to a definite area of from 5 to 15 acres. The men of each group fell the trees, saw them into proper lengths, peel the bark from the stulls, and dispose of the brush. In Forest Service timber sales the latter must be burned. During the safe months of the year, from October 1 to June 1, the men burn the brush as the cutting proceeds, but in summer they pile it for burning in the fall. Stumps are cut low, usually from 4 to 12 inches high. In winter, holes from 4 to 6 feet deep often have to be shoveled out to reach the proper point for cutting the trees. Although it is difficult to work under such conditions, particularly since the days are short and are likely to be stormy, work usually goes on throughout the year. Based on data obtained in connection with a sale at French Gulch, on the Deerlodge National Forest, the cost per thousand board feet of producing stulls amounts to $4.56. This includes shoveling snow, felling and trimming the trees, disposing of the brush, cutting the timber into stull lengths, and peeling. Fifteen per cent of the total cost is chargeable to snow disposal, while the largest single item is peeling, which costs $1.55 per thousand board feet, or 34 per cent of the total. The complete distribution of time in stull making at French Gulch, Mont., was as follows:

Operation.	Time spent in producing 1,000 board feet.	Cost per 1,000 feet.	Per cent of total cost.
	Minutes.		
Shoveling snow	72	$0.68	15
Felling trees	50	.48	10
Trimming trees	20	.19	4
Brush disposal, piling and burning	77	.73	16
Cutting into stull lengths	100	.93	21
Peeling	165	1.55	34
Total	484	4.56	100

SKIDDING AND HAULING.

After the trees have been felled and cut into the proper lengths, the logs, ties, mine timbers, and other products are skidded with teams or single horses into skidways along the hauling roads or other line of transportation. Whatever brush cutting or removal of down timber is necessary to open the way for skidding it is done either by swampers or by the skidders themselves. Where logging is easy and the distance short, tie cutters often skid their own ties on a light hand-sled over the snow, hauling about 10 ties to the load. Ties cut from trees near a stream which is to be driven or a main logging road are nearly always "hand-banked" in this manner. In Forest

Service timber sales the different classes of material are often scaled or counted by forest officers before being skidded. This scale is accepted by purchasers as a basis of settlement with the choppers.

In nearly all operations most of the hauling from the skidway to the flume, river, or railroad is done with sleighs on snow roads. The use of sleighs, which is possible from four to six months in the year, is by far the most economical and efficient method of hauling. Sometimes, however, where the haul is short and good roads are easily made, the material is carried on heavy trucks over the bare ground. This latter method is most common in small operations where a constant supply of logs and ties is required.

Chutes are sometimes used to get the products down steep grades to the main line of transportation.

TRANSPORTATION TO MILL.

In the smaller logging operations ties and mine timbers are usually hauled direct from the skidway to the railroad, shipping point, or market; the logs direct to the mill. In large operations, however, where the timber must be transported for from 20 to 100 miles or more, the method of transportation will depend upon the character of the area which is being logged. Ordinarily, the mountainous nature of the lodgepole region and the character of the timber prevent the use of logging railroads. Where the timber must be transported over a long distance it is a common practice to float it down some stream. Ties can be driven in streams which are too small to carry saw logs, which gives tie logging a decided advantage. Many small creeks have been made driveable for ties during the spring high water with only a little work in clearing the channel. In the larger streams of Wyoming and Colorado all classes of material have been driven for distances of 100 miles or more.

For shorter distances flumes have occasionally been used to good advantage, and in the future will undoubtedly play a more important part in the transportation of lodgepole pine. All the material from the French Gulch timber sale on the Deerlodge National Forest is removed by a flume about 18 miles long crossing the Continental Divide. The timber from above is hauled on sleds or trucks or is chuted down to the flume, where it is banked for fluming during the open season, which usually lasts from about May 1 to November 1. The timber from below is first banked along a tramway, up which the loaded cars are later hauled by a cable, operated by a stationary engine, to the banking grounds above the flume. A large proportion of this timber is delivered at the foot of the tram by means of secondary flumes located considerably below the main flume. The latter is V-shaped, with 24-inch sides. About 100,000 board feet of lumber per mile were used in its construction, and the original cost per mile was approximately $4,000. It has one tunnel 685 feet long, 29 tres-

tles over 25 feet high, the highest being 72 feet and the longest 775 feet, and 20 rock cuts from 8 to 20 feet deep. The minimum grade is one-half of 1 per cent and the maximum 12½ per cent. The sharpest curve is 20°. The flume carries from 200 to 800 inches of water, the supply of which is maintained by frequent feeders from small streams along its length. It can handle stulls up to 18 inches in diameter and poles up to 30 feet long, and has a capacity of about 1,800 stulls, 2,200 converter poles, 6,000 lagging poles, or 170 cords of wood in 10 hours. It is operated on the average for about 170 days each year. Operation costs, including rolling in, tending, and loading the material on cars at the dump, amount to $90 a day, to which must be added $70 a day for depreciation and maintenance. The secondary flumes have 18-inch sides, and the largest stull handled is 15 inches in diameter. They are more lightly built than the main flume, with about 33,000 board feet of lumber per mile, and cost about $1,500 per mile.

A similar V-shaped flume, 25 miles long, has been used for the last 7 years on the Bighorn National Forest for transporting ties, props, and logs from the woods to the mill and railroad. The larger logs are slabbed in a small sawmill at the head of the flume before being sent down.

MILLING.

Sawmill equipment used in lodgepole-pine operations does not differ from the usual type employed in the Rocky Mountains. Most of the lumber is cut by small mills, with a daily capacity of from 10,000 to 20,000 board feet, equipped with a single circular head saw, edger, trimmer, and sometimes a planer. In the few larger mills which cut lodgepole pine, band re-saws are used in conjunction with a circular head saw, and in addition, there is the usual equipment for making lath, flooring, siding, and other classes of finished lumber. In nearly all operations some sawed ties are turned out by the mill in addition to the hewed ties made in the woods.

COSTS AND SELLING PRICES.

The cost of producing lodgepole-pine lumber, ties, and props varies widely with topography, the character of the stand, and the size and efficiency of the operation. An idea of the probable expense incident to a lodgepole-pine operation can be best obtained from a statement of the average range of cost under various conditions, together with definite figures for a few specific operations. The range of cost for lumber, ties, and props in Wyoming and Colorado, under ordinary logging conditions and distances to market, is shown in Table 8. The cost of stumpage and such overhead charges as depreciation, taxes, insurance, and selling are not included, since these must be calculated for each individual case.

TABLE 8.—*Range in cost of production of lodgepole-pine saw timber, railroad ties, and mine props in Wyoming and Colorado.*

Operation.	Saw timber (log scale).	Railroad ties (standard gauge).	Mine props (all lengths).
	Per thousand board feet.	*Per tie.*	*Per linear foot.*
Felling, cutting, and trimming	$1. 00–$1. 50	$0. 12–$0. 16	$0. 0020–$0. 0050
Brush piling or lopping	. 25– . 50	. 01– . 02	. 0005– . 0010
Skidding	. 75– 2. 00	. 01– . 04	. 0005– . 0015
Hauling to flume, river, railroad, or main road [1]	1. 00– 2. 50	. 02– . 09	. 0010– . 0020
Fluming, driving, railroading, or hauling on main road	1. 00– 3. 00	. 03– . 10	. 0010– . 0080
Milling, piling, and delivering at market	4. 00– 7. 00		
Loading on cars at market point		. 02– . 03	. 0010– . 0020
Total cost at market [2]	8. 00–16. 50	. 21– . 44	. 0060– . 0195

[1] Includes building winter roads. [2] Without stumpage or overhead charges.

The figures which follow show the cost of an operation on private lands adjacent to the Arapaho National Forest, in Colorado, where 600,000 feet of logs were cut into rough boards and dimension material. Although in the actual operation no disposal was made of brush or débris, an item of 50 cents per thousand board feet has been included to make the cost comparable to similar operations on the National Forests, where brush piling is required. The stumpage price has been arbitrarily placed at $2 per thousand board feet.

	Per thousand board feet.
Felling and bucking into logs (cutting crew of 2 men, who also trim trees)	$1. 21
Piling brush (done by separate crew of 1 or 2 men)	. 50
Skidding (skidders do necessary swamping; maximum skid 500 feet; average 250 feet)	. 77
Hauling logs to mill (haul on sleds; average distance 1¼ miles)	. 84
Road building (roads for winter hauling only)	. 13
Construction of logging camp	. 13
Blacksmithing and repairing	. 11
Supervision and accounting (includes wages of woods foreman)	. 30
Decking at mill	. 18
Depreciation of equipment (covers logging equipment only)	. 02
Sawing (includes depreciation, taxes, and other charges on sawmill)	2. 25
Yarding lumber at mill	. 35
Hauling lumber to railroad (sled haul 4 miles to railroad)	1. 00
Loading on cars	. 50
Freight to market	2. 75
Stumpage	2. 00
Total cost at market	13. 04
Selling price, mill run at market	15. 00
Net profit (15 per cent on the operating cost) per thousand board feet	1. 96

The following appraisal of conversion costs and stumpage prices for a block of pure lodgepole pine on one of the National Forests in Wyoming may be taken as typical of the larger operations. This sale would involve the cutting within a period of 5 years of approximately 45,000,000 board feet, of which about 33,000,000 feet is suitable for ties and the remainder for saw timber.

Estimated conversion costs and stumpage value of tie timber.

	Firsts.	Seconds.
Depreciation on improvements and equipment	$0.020	$0.0019
Maintenance of improvements and equipment	.018	.0020
Overhead expenses (office, supervision, sales, insurance, etc.)	.025	.0027
Current operating expenses:		
Making (felling, bucking, hewing)	.150	.100
Brush disposal and cutting defective timber	.030	.030
Hauling and banking	.060	.060
Driving and booming	.072	.072
Loading	.018	.018
Total cost of production	.393	.2866
Average cost (90 per cent first class; 10 per cent second class)	$0.3824	
Average price received, f. o. b. cars	.62	
Difference for profit and stumpage	.2376	
Stumpage value, allowing 20 per cent profit	.13	

Conversion costs and stumpage value of saw timber.

Logging:		Per thousand board feet log scale.
Depreciation on improvements and equipment		$0.51
Maintenance of improvements and equipment		.35
Overhead expenses (supervision, office, scaling, etc.)		.40
Current operating expenses—		
Felling and bucking	$1.00	
Swamping and skidding	1.10	
Brush disposal and defective timber	.75	
Temporary roads	.35	
Hauling and banking	1.45	
Driving and booming	1.12	
		5.77
Total cost of logs at mill		7.03

Milling and marketing:	Per thousand board feet. Lumber tally.	Log scale.[1]
Depreciation on improvements and equipment	$0.58	$0.70
Maintenance of improvements and equipment	.23	.28
Overhead expenses (sales, insurance, supervision, office, etc.)	.54	.65
Current operating expenses—		
Milling	2.18	2.62
Yarding	.54	.65
Planing and finishing	.83	1.00
Grading and loading	.55	.66
Total milling and marketing	5.45	6.56

[1] The amount of lumber actually sawed out at the mill is estimated to overrun that shown by the log scale by 20 per cent. Consequently the figures in this column are obtained by increasing by 20 per cent the costs per 1,000 board feet as shown by the lumber tally.

	Per thousand board feet log scale.
Summary:	
Logging	$7.03
Milling and marketing	6.56
Total cost, on cars	13.59
Average sale price per thousand board feet, mill run	15.80
Average sale price per 1,200 feet mill run [1]	18.96
Difference for profit and stumpage	5.37
Stumpage value, allowing 25 per cent profit	1.58

Table 9 gives in detail for a representative part of the French Gulch timber sale on the Deerlodge National Forest, Mont., the cost of production of various-sized stulls, converter poles, lagging poles, and cordwood. Table 10 shows the market price received for the various products, together with the net profit per piece or per cord. The figures per thousand board feet run high for the smaller pieces because of their extremely low board-foot contents.

TABLE 9.—*Itemized cost of production of lodgepole-pine stulls, converter poles, lagging poles, and cordwood; French Gulch timber sale, Deerlodge National Forest, Mont.*

Product.	Size.		Stumpage price.	Cutting, peeling, and brush disposal.[2]	Skidding 100 yards.[2]	Hauling 1 mile to flume.[2]	Fluming 15 miles and loading on cars.	Freight to market at 3 cents per 100 lbs.	Overhead charges, interest, etc.[3]	Total cost of production.
	Length.	Top diameter.								
	Feet.	*Inches.*								
Stulls	14	5	$0.02	$0.06	$0.05	$0.06	$0.05		$0.01	$0.25
		6	.04	.08	.05	.06	.05	$0.03	.01	.32
		7	.08	.08	.05	.06	.06	.04	.03	.40
		8	.08	.16	.05	.10	.07	.06	.03	.55
		9	.12	.16	.05	.10	.08	.07	.05	.63
		10	.16	.16	.05	.10	.09	.09	.06	.71
		11	.20	.16	.05	.10	.10	.11	.07	.79
		12	.28	.16	.05	.10	.11	.13	.10	.93
		13	.32	.16	.05	.10	.12	.15	.12	1.02
		14	.40	.16	.05	.10	.13	.17	.15	1.16
		15	.48	.16	.05	.10	.14	.20	.19	1.32
		16	.56	.16	.05	.10	.15	.22	.21	1.45
		17	.64	.16	.05	.10	.16	.25	.25	1.61
		18	.76	.16	.05	.10	.17	.28	.30	1.82
	16	6	.08	.09	.05	.06	.06	.04	.03	.41
		7	.12	.10	.05	.06	.07	.06	.05	.51
		8	.12	.18	.05	.10	.08	.07	.05	.65
		9	.16	.18	.05	.10	.09	.09	.06	.73
		10	.24	.18	.05	.10	.10	.11	.08	.86
		11	.28	.18	.05	.10	.11	.13	.10	.95
		12	.32	.18	.05	.10	.12	.16	.12	1.05
		13	.40	.18	.05	.10	.13	.18	.15	1.19
		14	.44	.18	.05	.10	.14	.20	.17	1.28
		15	.56	.18	.05	.10	.15	.24	.21	1.49
		16	.64	.18	.05	.10	.16	.26	.25	1.64
		17	.72	.18	.05	.10	.17	.30	.30	1.82
		18	.84	.18	.05	.10	.18	.33	.30	1.98
Converter poles	24	3½	.10	.035	.05	.06	.08	.03	.03	.385
Lagging poles	16	2	.03	.0175	.01	.015	.02	.01	.012	.115
Cordwood		[4] 6	.50	1.25		.75	.85	.90	.60	4.85

[1] Since the mill overrun is 20 per cent, 1,200 board feet mill run scale will equal 1,000 feet log scale. The mill run selling price of $15.80 per 1,000 board feet must, therefore, be increased by 20 per cent to make it comparable with the other figures, which are based on log scale.
[2] By contract.
[3] 8 per cent interest on $100,000 and $10,000 annual overhead charges.
[4] Average.

TABLE 10.—*Total cost of production, market price, and net profit for lodgepole-pine stulls, converter poles, lagging poles, and cordwood. Deerlodge National Forest, Mont.*

Product.	Size.		Per cent of entire cut by pieces.[1]	Cost of production per piece.[2]	Market price.[3]			Profit per piece.	Price at which square timber must sell per thousand board feet in Butte to equal round in price per cubic foot.
	Length.	Top diameter.			Per piece.	Per cubic foot.	Per 1,000 board feet.[4]		
	Feet.	*In.*							
Stulls	14	5	18.24	$0.25	$0.28			$0.03	
		6	16.76	.32	.36	$0.100	$36.00	.04	$8.33
		7	7.19	.40	.50	.111	25.00	.10	9.25
		8	4.30	.55	.71	.118	35.50	.16	9.84
		9	1.85	.63	.85	.112	28.33	.22	9.33
		10	.86	.71	1.00	.106	25.00	.29	8.84
		11	.39	.79	1.14	.100	22.80	.35	8.33
		12	.37	.93	1.41	.105	20.13	.48	8.75
		13	.12	1.02	1.55	.099	19.37	.53	8.25
		14	.07	1.16	1.72	.096	17.20	.56	8.00
		15	.04	1.32	1.90	.094	15.83	.58	7.73
		16	.02	1.45	2.07	.091	14.78	.62	7.58
		17	.01	1.61	2.25	.088	14.06	.64	7.33
		18	.005	1.82	2.46	.086	12.94	.64	7.16
	16	6	10.42	.41	.45	.102	22.50	.04	8.50
		7	11.12	.51	.59	.102	19.67	.06	8.50
		8	10.09	.65	.86	.116	28.67	.21	9.67
		9	7.18	.73	1.00	.109	25.00	.27	9.09
		10	4.74	.86	1.18	.104	19.67	.32	8.67
		11	2.76	.95	1.33	.099	19.00	.38	8.25
		12	1.69	1.05	1.45	.091	18.12	.40	7.58
		13	.89	1.19	1.63	.089	16.30	.44	7.42
		14	.43	1.28	1.76	.084	16.00	.48	7.00
		15	.22	1.49	1.98	.084	14.13	.49	7.00
		16	.12	1.64	2.15	.081	13.43	.51	6.75
		17	.06	1.82	2.33	.078	12.94	.51	6.50
		18	.05	1.98	2.54	.076	12.09	.56	6.35
Converter poles	24	3½		.385	.385	.123		.015	
Lagging poles	16	2		.115	.12	.12		.005	
Cordwood		[5]6		4.85	5.00	.063		.15	

[1] Based on 262,621 pieces scaled in 1910–11.
[2] From Table 8.
[3] At the rocker stull framing plant, near Butte, for the stulls; at the Anaconda smelter for the converter poles; and at Butte for the lagging poles and cordwood, etc.
[4] Derived from the figures per piece by using the contents in board feet of pieces of different sizes given in Table 5.
[5] Average.

The stumpage price per piece shown in Table 9 is equivalent to one of $4 per thousand board feet. This price has been in effect for several years in the principal sales on the Deerlodge National Forest. When the prices for the various products were reduced to a cubic-foot basis, however, considerable irregularity was disclosed. Small-dimension material, for which the demand is relatively light, was bringing a higher price per cubic foot than the larger-dimension material, for which the demand is great and which takes longer and is more expensive to produce. Since the timber was not being sold for lumber nor actually scaled by the Decimal C rule, it was considered advisable to adopt a set of piece-rate prices, based on cubic-foot contents and increasing with the diameter and length of the

individual pieces. Table 11 shows the prices now in effect in lodgepole sales similar to those on the Deerlodge Forest. The Government obtains practically the same total return on all classes of material cut annually. The lower prices on smaller-sized material tend to encourage thinnings, while the higher prices for the larger timber offset the decreased returns from the former.

TABLE 11.—*Rate per cubic foot and price per piece for lodgepole-pine timber, Deerlodge National Forest, Mont.*

Top diameter.	Length, 10 feet.		Length, 12 feet.		Length, 14 feet.		Length, 16 feet.		Length, 18 feet.	
	Rate per cubic foot.	Price per piece.	Rate per cubic foot.	Price per piece.	Rate per cubic foot.	Price per piece.	Rate per cubic foot.	Price per piece.	Rate per cubic foot.	Price per piece.
Inches.	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*
4	0.75	1	1.0	1.5	0.75	1.5	0.75	2	0.75	2
5	.8	1	1.0	2	.8	2.5	.8	3	.9	4
6	1.0	2	1.1	3	1.1	4.0	1.2	6	1.3	7
7	1.4	5	1.4	6	1.4	6.0	1.5	8	1.6	11
8	1.7	7	1.8	9	1.9	11.0	1.9	14	1.9	16
9	2.0	10	2.0	13	2.0	15.0	2.0	18	2.0	21
10	2.1	13	2.1	17	2.1	20.0	2.1	24	2.1	27
11	2.1	16	2.2	21	2.2	25.0	2.2	30	2.2	34
12	...	...	2.2	24	2.3	31.0	2.3	36	2.3	43
13	...	...	2.3	30	2.4	37.0	2.4	44	2.4	52
14	...	...	2.4	36	2.5	45.0	2.5	52	2.5	60
15	...	...	...	...	2.6	53.0	2.6	62	2.6	71
16	...	...	...	...	2.7	62.0	2.7	71	2.7	83
17	...	...	...	...	2.8	71.0	2.8	84	2.8	95
18	...	...	...	...	2.9	83.0	2.9	98	2.9	109

Top diameter.	Length, 20 feet.		Length, 25 feet.		Length, 30 feet.		Length, 35 feet.		Length, 40 feet.	
	Rate per cubic foot.	Price per piece.	Rate per cubic foot.	Price per piece.	Rate per cubic foot.	Price per piece.	Rate per cubic foot.	Price per piece.	Rate per cubic foot.	Price per piece.
Inches.	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*
4	0.8	2.5	0.8	4	0.9	6	...	...	...	...
5	1.0	5	1.0	6	1.2	10	...	...	...	...
6	1.3	8	1.4	11	1.5	16	1.7	23	1.8	31
7	1.6	13	1.7	18	1.9	26	1.9	32	2.0	44
8	1.9	19	2.0	26	2.0	35	2.0	44	2.1	57
9	2.0	24	2.1	34	2.1	45	2.1	55	2.2	73
10	2.1	31	2.2	41	...	...	...	...	...	...
11	2.2	39	2.3	54	...	...	...	...	...	...
12	2.3	49	2.4	64	...	...	...	...	...	...
13	2.4	59	2.5	79	...	...	...	...	...	...
14	2.5	70	2.6	95	...	...	...	...	...	...
15	2.6	81	2.7	110	...	...	...	...	...	...
16	2.7	94	2.8	133	...	...	...	...	...	...
17	2.8	111	2.9	150	...	...	...	...	...	...
18	2.9	125	...	...	...	...	...	...	...	...

Lower stumpage prices than those shown are often received for lodgepole-pine timber in many places where only small quantities are required for local use. In Montana the minimum price is approximately $2.50 per thousand board feet. The price of lodgepole-pine stumpage in Forest Service timber sales ranges between this figure and $4.50 per thousand. On State and private lands the average prices are about the same, though in some cases the minimum may be lower than on the National Forests.

The market prices for lodgepole-pine products vary a great deal in different localities. The price of ties is usually fixed by agreements between tie contractors and the railroads. During the last 10 years, however, there has been a steady rise in the prices paid for lodgepole-pine ties. About 5 years ago one large company held a contract to deliver a minimum of 500,000 ties per year at 39 cents on the track, and for all over the minimum number was to receive 45 cents each. Recently the prices paid have ranged from 50 to 65 cents each for first-class ties.

Mine props are usually sold by the linear foot, the pieces varying in diameter from 3 to 6 inches at the smaller end, and in length from 3½ to 16 feet. In general, prices range from 1 to 5 cents per linear foot, according, in some measure, to the size of the prop. At one place in Colorado, for example, the price paid f. o. b. cars is 1 cent per linear foot for 16-foot props, and 1.5 cents per linear foot for 7, 8, and 10 foot props with the small end not less than 4 inches. Representative prices for stulls, lagging, and converter poles in the vicinity of Butte, Mont., are shown in Table 9. Wood usually sells from $5 or $6 per cord delivered to the consumer in town.

In many places there are strong local markets for lodgepole-pine lumber. While the yearly demand is not large, the prices paid are good. In one locality the mill run sells for $17.50 per thousand board feet, and in another for $20.50. While in most places mill run is seldom sold for less than from $15 to $16 per thousand board feet, yet where lumber is considered a by-product, such material is often sold at only a small profit or even at cost.

CHARCOAL MAKING.

In making charcoal the first work is to grade and level up the ground where the pit is to be located. The same place is used two or three times to save work in grading. The wood is cut in 10-foot lengths and hauled to the place where it is to be burned. Each pit accommodates about 50 cords of wood properly stacked and covered with brush, leaves, and dirt. Very complete utilization is secured, since even small branches and twigs are used to fill in chinks and for covering. The actual burning takes about 20 days. Forty bushels of charcoal are produced per cord of wood, weighing 13½ pounds per bushel. Charcoal makers usually work in pairs, for when the pit is burning it must be watched night and day to guard against blow-outs and to change the drafts with varying weather conditions. Two pits are usually burned at one time, a pair of men guarding both.

In charcoal operations near Bernice, Mont., the finished product has to be hauled 8 miles to the railroad at Bernice. One round trip is made a day, with an average haul of 400 bushels. The charcoal is then shipped by freight to Helena in carload lots of 1,600 bushels, at a rate of 15 cents per hundred pounds. Itemized costs of charcoal making in the vicinity of Bernice are as follows:

	Per cord of wood.		Per bushel of charcoal.	
Stumpage		$0.50		$0.0125
Cutting and burning:				
Grading	$0.17		$0.0043	
Cutting	.90		.0225	
Hauling	.45		.0112	
Covering	.56		.0140	
Burning	1.12		.0280	
		3.20		.0800
Hauling to railroad		1.20		.0300
Loading on cars		.05		.0012
Freight, Bernice to Helena		.81		.0202
Total		5.76		.1439
Price received at Helena		6.00		.1500

MANAGEMENT.

OBJECTS.

The two main objects to keep in mind in the management of lodgepole-pine forests are (1) watershed protection and (2) a maximum sustained yield of merchantable timber of the most desirable sizes.

Its wide range and the fact that most of the stands are located at the higher elevations, where rainfall is greatest and the slopes steep, give lodgepole pine a peculiar importance in regulating the flow of streams which have their headwaters in the region. Even the Mississippi receives a considerable part of its summer supply of water from some of these streams. Thus the value of lodgepole-pine forests for the conservation of water is probably as great as their value for timber production, especially when one considers their slow growth and relatively small yield. Nevertheless, lodgepole pine is an important timber tree, and every effort should be made to produce the greatest possible amount of merchantable timber consistent with the maintenance of an adequate forest cover on the watersheds. Many classes of material produced by lodgepole-pine stands, from small poles to the largest timber, can now be marketed, though the demand for each class is not proportionate to the supply. Small stulls, mine props, lagging, converter poles, fence poles, and cordwood, for example, are produced in far greater quantities than the market can absorb, while the demand for large stulls, ties, telephone poles, and saw timber is much greater in proportion to the available supply of this class of material. For this reason every effort should be made to produce large trees, 9 inches or more in diameter. There will inevitably be produced at the same time sufficient small timber to meet every demand.

Throughout most of the lodgepole-pine belt the species should be perpetuated on areas now occupied by it. Exceptions to this rule, however, should be made at the lower and upper edges of the belt, where other species are better suited to the conditions. Thus at the lower elevations the stand should be allowed to revert to Douglas fir and at the upper to Engelmann spruce. Between these two extremes, however, lodgepole pine should be favored against these and such other species as may occur in mixture with it.

ROTATION.

The length of the rotation, which is the period represented by the age of the stand at the time it is to be cut, is determined by the rate of growth of the species under consideration and the purpose for which it is to be used. In the case of lodgepole pine, the tree's slow growth and the need for producing as large size material as possible necessitate a comparatively long rotation. Table 11 shows that the mean annual growth in cubic feet of normal stands in Montana, measured to about 2½ inches in the top, culminates at from 70 to 90 years. A rotation of this length, however, gives few trees 9 inches or more in diameter, and is therefore too short. For material scaled to a 6-inch top diameter limit the mean annual growth in board feet culminates at 130 years, and for material scaled to 8 inches in the top, at from 200 to 210 years. At 130 years only about two-fifths of the scale material is 8 inches or more in diameter at the top end, which is too small a proportion, while at 200 years nearly nine-tenths of the material is of large size, which is more than is needed. The mean annual growth in board feet to a 6-inch top is nearly at its maximum at 140 years, when 53 per cent of the scale material is 8 inches or more in top diameter. This is about as small a proportion of large material as a mature stand ought to produce; at the same time a rotation of 140 years is not unreasonably long. It would appear, therefore, that such a rotation is the best for normally stocked lodgepole stands on average sites in Montana. While yield figures for normal stands in Wyoming and Colorado are not available, it is probable that a rotation of approximately the same length would be satisfactory in these States for the production of mine timbers and ties.

TABLE 12.[1]—*Mean annual growth per acre of normal stands of lodgepole pine on average sites (quality II), at various ages, Deerlodge National Forest, Mont.*

Age.	Mean annual growth.			Amount of scale material 8 inches and over in top diameter.
	Entire tree, top diameter 2½ inches.	Scale material.		
		Top diameter 6 inches.	Top diameter 8 inches.	
Years.	*Cubic feet.*	*Board feet.*	*Board feet.*	*Per cent.*
60	40	81	0	0
70	42	92	0	0
80	42	100	0	0
90	42	105	0	0
100	41	109	15	14
110	39	112	27	24
120	37	113	38	34
130	35	114	49	43
140	33	113	60	53
140 to 200[2]				
200	24	103	90	87
210	23	102	90	88
220	22	100	89	89

[1] Based on Table 9, Department of Agriculture Bulletin 154, "The Life History of Lodgepole Pine in the Rocky Mountains." While the board feet figures are not strictly accurate, they are sufficiently so to serve as a guide in determining the length of rotation.

[2] Between 140 and 200 years there is a constant decrease in the mean annual growth in cubic feet and in board feet to a top diameter of 6 inches, and a constant increase in the mean annual growth in board feet to a top diameter of 8 inches.

It is impossible to fix a single rotation for the ordinary stands now found in the lodgepole-pine region, because of their variable density. Some of the more open stands are ready for cutting before they have reached the age of 140 years, while many of the denser ones will never produce large-sized material without a thinning. For average, well-stocked, unthinned stands on average sites, however, a cutting at 140 years should yield 8,000 or 10,000 board feet per acre, with a fair proportion of large-sized timber, and at the same time leave from 200 to 500 of the smaller trees for future growth. On the better sites the rotation would be shorter and on the poorer sites longer.

METHODS OF CUTTING.

DETERMINING FACTORS.

A number of things have to be considered in determining the best method of cutting lodgepole pine. The forest must be left in such a condition that it will continue to furnish protection to the watershed, the increment of the whole stand must be increased as much as possible, the trees which are left must not be unduly exposed to injury from windfall or sun scald, and the material removed must be of sizes for which there is a ready market. The object of the cutting must also be considered.

HISTORY OF FRENCH GULCH TIMBER SALE.

In order to give a clear idea of the present plan of management for lodgepole pine on the National Forests, the methods employed in the French Gulch timber sale on the Deerlodge National Forest will be briefly described. Owing to the Forest's proximity to Butte, where material of all sizes can be disposed of, it has been practicable, on limited areas at least, to use a number of different systems of cutting. The first cutting followed the selection system.[1] Although the stand was opened up rather heavily in places, there has been but little windfall and the trees are growing faster than before the cutting.[2] This system was not used for a sufficient length of time early in the operation, however, to give it a thorough trial. At about the same time the single-tree system was also practiced in some places, but with unsatisfactory results.

The first definite marking rules were promulgated in October, 1906. They provided for cutting clean strips 150 feet wide, running with the slope, with 75-foot strips between. These latter were divided into blocks 75 feet square, alternate blocks being cut

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[1] Properly speaking, the selection system is one used in many-aged stands of tolerant species, from which the large trees are removed in order to admit light to the smaller ones and to start reproduction. The system used on the French Gulch sale area was really a culling or form of partial cutting, but the term "selection system" is the one applied to this method in the lodgepole-pine region.

[2] French Gulch is in the Anaconda smelter-smoke zone, which tends very largely to offset the usual benefits which follow the opening up of a stand.

clean and the remainder left for seed. Even in the seed blocks thinnings were made to remove lagging, converter poles, and large stull trees, so that the seed groups finally consisted of from 30 to 60 trees ranging from 7 to 11 inches in diameter. In exposed situations over 90 per cent of the trees left have been blown down, and many others have died from sun scald or from the drying out of the soil. In the more sheltered situations, particularly where the original stand had been somewhat open, windfall has been much less. This heavy loss from windfall quickly demonstrated the impractibility of such a system for general use in lodgepole-pine stands. These cuttings were not a fair test of the wind firmness of the species, however, for to reduce the number of trees per acre of any species from 500 or 1,000 to about 50, particularly when the individual trees were tall and slender, could hardly result otherwise than in excessive windfall.

The next change in the marking system naturally aimed to eliminate windfall. In the spring of 1909 the strip system was applied. The timber was clean cut in strips, with seed strips from 100 to 150 feet wide left absolutely intact between them. The width of the clean-cut areas was from one to three times that of the seed strips. This system proved successful in reducing windfall to a negligible amount, but in other respects had no advantage over the seed-tree group system. In both systems the operator gradually accumulated a surplus of cordwood and small stulls in excess of the market demand, while the Government lost from the clean-cut areas many small, thrifty trees capable of rapidly developing into large material under better management. At the same time there remained in the seed strips many large, slowly growing trees wanted by the operator and not of use in the stand except to prevent windfall. Neither of the systems is satisfactory in regard to watershed protection, nor does either tend to increase the volume or better the quality of the succeeding stand.

Another important drawback to the systems mentioned was their lack of adaptability to the great variety of conditions found on the sale area. Overdense stands of lagging and converter poles, badly in need of thinning, remained untouched, because a sufficient amount of such material was being obtained from the clear-cut areas. Overdense and moderately dense even-aged stands, uneven-aged stands, and old and young stands were all cut in exactly the same way. For this reason the system of cutting was still further modified in the fall of 1910 and again slightly modified in the summer of 1913. The present marking rules are as follows:

FIG. 1.—SINGLE SEED-TREE METHOD OF CUTTING EMPLOYED EARLY IN THE FRENCH GULCH SALE.

Much windfall resulted, and many trees died of sun scald when exposed to full light. Most of the windthrown trees had been utilized before the picture was taken.

FIG. 2.—SELECTION CUTTING ON THE FRENCH GULCH SALE.

The stand was heavily thinned in 1906. Remaining trees are well spaced and already show increased growth. This thinning was somewhat heavier than those now being made in selection cuttings, but shows very little windfall.

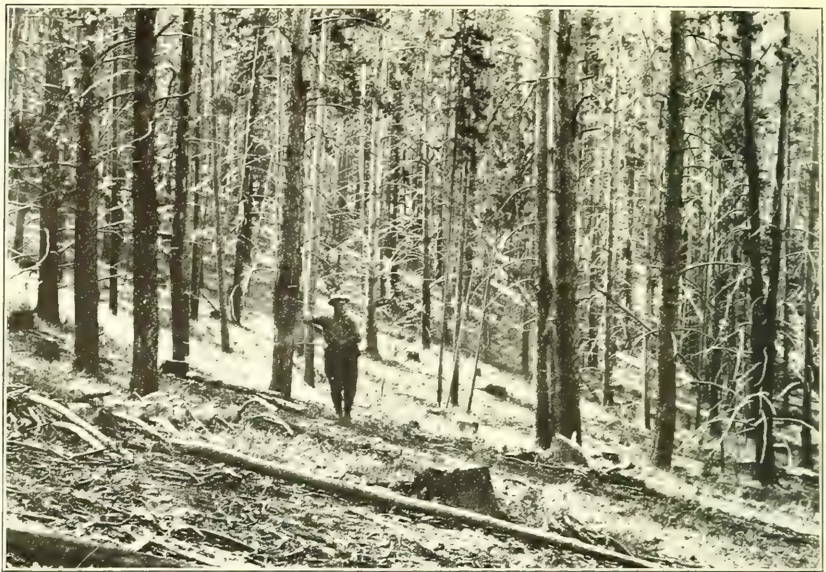

FIG. 1.—SELECTION CUTTING ON THE FRENCH GULCH SALE, WITH BRUSH BURNED AND PRODUCTS REMOVED.

Note low stumps.

FIG. 2.—SELECTION CUTTING ON THE FRENCH GULCH SALE IN WHICH NEARLY ALL TREES WHICH WOULD MAKE 8-INCH STULLS WERE REMOVED.

Note side branches and short clear lengths.

MARKING RULES FOR LODGEPOLE-PINE STANDS ON THE DEERLODGE NATIONAL FOREST.

CLASSIFICATION OF STANDS.

1. *Over-mature stands:*

Such stands are over 160 years in age, contain mainly trees 10 inches or over in diameter, which have evidently passed maturity and are practically at a standstill, if not on the decline.

A very large proportion of the cubic-foot volume of the stand consists of material 8 inches and over in diameter.

In openings which have occurred in the stand from various causes there are frequently groups of young or middle-aged trees which are thrifty and growing fairly rapidly. Owing to the thinning out of the crown cover with old age, there is also usually more or less reproduction on the ground. An example of this class of stands is that found in Julius Gulch, on the French Gulch sale area.

2. *Mature stands:*

Stands of this class usually range in age from 120 to 160 years, but may frequently be older than 160 and in a few cases younger than 120, depending mainly upon the stage of development of the stand, as a whole, as to the production of trees 10 inches or over in diameter.

This classification aims to include stands which contain a large number of trees 10 inches and over in diameter which are now ready for cutting, with a considerable proportion of the whole number of trees, usually over 60 per cent, below 10 inches in diameter and still with crowns sufficiently thrifty to respond with a material increase in the rate of growth to openings which may be made in the stand.

Such stands may range up to 180 or 190 years in age where they have been somewhat crowded in youth.

Groups of young growth are of more or less frequent occurrence in natural openings.

Examples of stands of this class are found in the Jabez Doney sale area, on Dry Gulch, in the Bernice district, and in the selection cuttings along American Gulch, below the main flume, on the French Gulch sale area.

3. *Immature stands:*

Usually under 120 years of age, but classified as young mainly because they do not yet contain any considerable proportion of trees which will yield 8-inch material.

This class is further divided into—

(*a*) Converter pole stands:

Ordinarily from 80 to 120 years in age, but may range up to an age of 160 years where the stand had its origin in overdense reproduction.

There are usually present a few trees from 7 to 10 inches in diameter, but most of the trees have a diameter of less than 8 inches.

Usually there is no reproduction coming in under such stands.

(*b*) Lagging stands:

Such stands usually range in age from 50 to 80 years, but, due to overdensity of reproduction, may be as old as 140 years.

Occasionally there are a few trees from 6 to 8 inches in diameter, but most of the trees are below 6 inches.

OBJECTS OF MARKING.

The main object of cutting done on the Deerlodge Forest will be to secure the greatest possible increase of increment for the Forest, as a whole, but not necessarily for each particular acre cut over considered by itself.

The overmature stands will be cut with the intention of removing the old timber now at a standstill and securing a stand of rapidly growing reproduction in its place.

Mature stands will be cut with the object of removing the larger trees now ripe in size for cutting and retaining the smaller trees so situated that many of them will grow to a diameter of over 9 inches within the next 20 to 50 years. Reproduction is not aimed at, although the manner of cutting will secure it in many openings and will hasten its growth in the many places where it already occurs.

Young stands will be handled by improvement thinnings, strictly with the idea of saving the most promising trees and giving them sufficient room to grow rapidly in the future to good size.

CLASSIFICATION OF EXPOSURES.

The following classification is made as a guide to the men doing the marking, with the object of adjusting the severity of the cutting, in the mature stands particularly, to the purpose of securing safety from windfall.

The prevailing wind direction is southwest for the Forest as a whole, although it may be modified locally by topography.

Especially moist and especially shallow soils increase the danger of windfall and should therefore be given consideration in classifying various areas as to exposure. The presence of former windfalls should also be considered.

Safe exposures:

In this classification are included the bottoms of gulches, as a rule, except where they lie parallel to the course of the prevailing wind for a considerable distance. Slopes to the north and east, or in any direction where short or unimportant and well protected by considerably higher ground not far to windward. Examples of such areas are the bottoms of the gulches and the slopes on the Divide Creek sale area.

Medium exposures:

This includes the larger flat areas, gentle, lower slopes to the south and west, and the minor ridge tops where protected by high hills or mountains not far to windward. Examples are the flats and gentle slopes to the west below the main flume at French Gulch, the minor ridge tops on Divide Creek, and the higher portion of the Dry Gulch sale area.

Great exposures:

The crests of exposed ridges and exposed slopes to south and west not protected by marked topography. Such areas would include the south and west face of Slide Rock Mountain and the ridge between Julius and Vanetti Gulches on the French Gulch sale area.

METHODS OF MARKING.

1. *Overmature—Clean cutting:*

Cut all timber merchantable under the terms of the contract excepting that under 7 inches diameter breast high.

Leave groups of smaller size trees and young growth as carefully preserved as possible.

Leave none of the larger trees as a protection against windfall.

The trees left, together with the seed already in the soil and in the cones of trees cut, will provide for reproduction.

2. *Mature—Selection cutting:*

Cutting will be done only to such a degree as, in the judgment of the marker, will leave the stand safe from windfall, particular attention being paid to exposure.

Cut the larger trees—all 14 inches and over—unless needed to prevent windfall.

Cut trees 10 to 13 inches, unless they are needed to prevent windfall, or unless they are especially sound, thrifty individuals standing where they will profit greatly by the amount of light which they are now receiving or will receive after cutting.

Cut 8 and 9 inch trees only when their removal is desirable for the good of the remaining stand, and when they are entirely acceptable to the operator.

Cut no converter poles or lagging trees, or trees of similar size (7 inches or under), whether green or dead, from stands of this classification. Such material may, however, be utilized at the option of the operator, from the tops of the trees designated for cutting, or from material cut from roadways, banking grounds, etc.

Excepting with the general consent of the operator, expressed as to definite areas, no tree which will not make at least one 8-inch–16-foot piece will be marked for cutting. On the other hand, all defective and limby trees, whose retention in the stand is not desired to prevent windfall, will be marked for cutting if they will yield one 8-inch–16-foot piece.

Small pockets of larger trees may be cut clean. Such patches should not ordinarily exceed a quarter acre in area and will usually be much smaller. These clean-cut patches should not exceed 20 per cent of the cutting area in mature stands, and the cutting in the timber around their edges should be lighter than usual to maintain the windfirmness of the whole stand.

The marker should have constantly in mind the object of leaving the stand in the best possible condition for increased growth after the cutting, for which purpose thrifty crowned trees should be left with as reasonable an amount of growing space as the limitations of the system as above set forth will permit.

Selection marking should be very light around the edges, especially the leeward edges, of parks or clean-cut areas an acre or more in extent.

On "safe" exposures, as defined above, no attention need be paid to windfall, since the other rules will leave sufficient timber on the ground to insure windfirmness of the stand.

On "medium" exposures the marking should be done about as it has been in the selection areas below the main flume at French Gulch, where there are left 70 per cent of the trees 3 inches and over, 62 per cent of the trees 6 inches and over, and 20 per cent of the trees 10 inches and over.

On "great" exposures the cutting should remove approximately 25 per cent less than from the "medium" exposures, or should leave approximately 80 per cent of the trees 3 inches and over, 70 per cent of the trees 6 inches and over, and 40 per cent of the trees 10 inches and over.

The foregoing are general rules as to the amount to be left, and must be adapted carefully to the exposure, soil moisture and depth, topography, and condition of the timber in each case, but the leaving of a sufficient stand to be safe from wind throw will be the primary consideration in all selection marking.

3. *Immature—Improvement thinning* with the object of retaining the best trees and leaving them in the best possible position to grow rapidly to large size.

(*a*) Converter-pole stands:

The marker will mentally select for leaving the best trees, straight, sound trees with considerable clear length and a good crown development for the most part, and will aim to leave such trees as evenly disposed as possible over the area, and at the rate of about 2 per square rod (320 per acre) as an ideal number. All other green trees which will make converter poles (4 to 6 inches diameter breast

high) will then be marked for cutting. No lagging trees will be marked for cutting, for such trees will not interfere with the growth of the larger trees especially selected for leaving. No dead trees will be cut unless they will produce at least one 8-inch–16-foot piece. On account of the difficulty of handling long poles in dense stands, the cutting of frequent skid roads is permissible.

Under this system of cutting no attention need be paid to windfall, for a sufficient number of larger trees together with a large number below converter-pole size will be left to withstand the wind.

(*b*) Lagging stands:

The marker will mentally select for leaving the best individual trees—so far as possible straight, sound trees, with either some clear length or at least without large limbs developed at the base of the tree—and will aim to leave such trees as evenly disposed as possible over the area, and at the rate of 3 per square rod (480 per acre) as an ideal number. All other *green* trees which will make lagging (3 to 5 inches diameter breast high) will then be marked for cutting. No dead lagging will be cut. The cutting of frequent skid roads is permissible. No attention need be paid to windfall.

The result of cutting under this selection system at French Gulch has been to leave a considerably larger number of trees on the ground than under the clear-cutting system, and so placed that the rate of growth of most of them will be increased. The proportion of cordwood and small stulls taken by the operator has been reduced and the total number of large stulls increased as indicated by the following figures:

	Per cent large (8 inches and over).		Per cent small (under 8 inches).	
	Selection cutting.	Clear cutting.	Selection cutting.	Clear cutting.
Number of stulls cut	57	37	43	63
Cubic foot volume of stulls cut	71	51	29	49
Board foot volume of stulls cut	76	57	24	43

By the present method of cutting, 2.67 cords, or their equivalent, are taken with each 100 large stulls; by the clear-cutting method, 4.95 cords were taken. In the selection cuttings, too, the average size of the large stulls is greater than was the case in the clear cuttings. The amount of material of various classes cut under the two systems is given in Table 13. The amount of material and the number of trees of various sizes cut and left by the selection system are shown in Tables 14 and 15.

TABLE 13.—*Material of various classes secured under selection cutting and clear cutting on a representative portion of the French Gulch sale, Deerlodge National Forest, Mont.*

[Average acre based on sample areas actually cut and scaled.]

	Selection cutting.						Clear cutting.	
	Cut.		Uncut.		Total.		Cut.	
	Number.	Volume.	Number.	Volume.	Number.	Volume.	Number.	Volume.
		Cubic feet.		*Cubic feet.*		*Cubic feet.*		*Cubic feet.*
Stulls 8 inches and over	176	1,670	67	546	243	2,216	238	2,135
Stulls under 8 inches	135	602	180	800	315	1,402	340	1,675
5-inch mine props	41	110	115	308	156	418	56	149
Converter poles	7	20	79	238	86	258	203	610
Lagging	89	89	106	106	195	195	303	303
Cordwood	3.3	266	1.9	150	5.2	416	7.8	624
Total		2,757		2,148		4,905		5,496

TABLE 14.—*Per cent of material cut and left in selection cuttings on the French Gulch sale, Deerlodge National Forest, Mont.*

	Per cent cut.	Per cent left.
Cubic-foot volume of stand	56	44
Board-foot volume of stand	64	36
Large stulls	72	28
Cubic-foot volume of large stulls in stand	75	25
Board-foot volume of large stulls in stand	76	24
Green trees 3 inches and over in diameter	30	70
Green trees 6 inches and over in diameter	38	62
Green trees 10 inches and over in diameter	80	20

TABLE 15.—*Number of trees cut and left on an average acre under the selection system, Deerlodge National Forest, Mont.*

Diameter breast-high.	Number of trees.			Diameter breast-high.	Number of trees.		
	Total.	Cut.	Left.		Total.	Cut.	Left.
Inches.				*Inches.*			
3	34	2	32	15	6	6	
4	55	5	50	16	4	4	
5	54	9	45	17	2	2	
6	53	4	49	18	1	1	
7	61	5	56	19	1	1	
8	54	8	46	20	.25	.25	
9	44	10	34	21			
10	31	16	15	22			
11	28	23	5	23	.25	.25	
12	20	17	3				
13	22	19	3	Total	483.5	145.5	338
14	13	13					

Average diameter of trees cut, 11.2 inches.
Average diameter of trees left, 6.8 inches.
30 per cent of trees 3 inches and over cut.
38 per cent of trees 6 inches and over cut.
80 per cent of trees 10 inches and over cut.

In order to determine precisely what form marking should assume at each particular place, a detailed map was made by the men who did the work. Besides showing the different kinds of stands, this map formed a valuable record of the area cut over. The cost of marking, including that of the map, averages about 8 cents per thousand feet. It costs more to mark the trees in winter than in summer, and more for the selection system than for clean-cutting. Compared with the cost in stands of such species as yellow pine, that for lodgepole pine is rather high, owing to the small size of the individual trees. It has been found advisable, with the present system of cutting, to mark rather lightly at first, marking again after the first trees have been cut. This causes no hardship to the operator, for the second marking is done before the choppers finish a strip. It costs slightly more than a single marking, but gives more satisfactory results. The marking rules for the Deerlodge are based upon the requirements of the Butte market. They aim not only to furnish the proper amount of each kind of material needed by the timber purchaser, but also to secure the maximum benefits in the way of increased growth, etc., for the Forest as a whole. This does not mean, of course, that each individual acre cut over is left in the best possible silvicultural condition. To do that, the operator would have to cut a greater proportion of small material than the market could absorb. The cutting in mature stands would yield all the lagging and converter poles needed, so that it would not be possible to secure the thinning of overdense immature stands. Lagging poles, for example, can be secured either by taking very badly suppressed or dead trees of the proper sizes from mature or overmature stands, or by thinning dense young stands. If they are taken from old stands no improvement in the rate of growth of the remaining trees will result; there will simply be a utilization of material which is either at a standstill or already dead. If, however, lagging poles are taken from overdense young stands, the remaining trees will be greatly benefited, the stand being changed from one in which the production of large material is going on very slowly to one in which it is comparatively rapid. For this reason, timber of small diameter should, so far as practicable, be taken in the form of thinnings from the younger stands.

Overmature stands of lodgepole pine on the Deerlodge Forest will not be cut absolutely clean. A number of trees less than 7 inches in diameter will be left on each area. Groups of young growth which have come up in openings will also be left, together with scattered, suppressed seedlings. The live trees which remain after the cutting and the sealed cones on the ground will furnish enough seed to start satisfactory reproduction in the open places. There may be occa-

sional small openings, however, which will not seed up for from 10 to 20 years. The result will be a new stand with a considerable range in age. A number of the 4, 5, and 6 inch trees left standing will undoubtedly be blown down. Such loss, however, will be far less than would be the case if a sufficient number of the larger trees were left uncut to insure the wind firmness of the smaller ones. In the latter event, there would probably be a severe windfall among the larger trees; the cost of logging would be increased, and a considerable part of the producing power of the soil would be lost for a time.

In mature stands, cut under the selection system, windfall will be negligible if the marking is carefully done. In many of the openings seedlings will start and grow vigorously; in other places, where a fair number of trees still remain on the ground, they will grow slowly until released by a later cutting; while in still others the stand will be too dense for reproduction to start. From 15 to 20 years later it will be possible to cut the stand again, at which time the process just outlined will be repeated. Later cuttings will completely remove the original stand, leaving one of many age classes, the latter largely in groups.

When immature stands of lodgepole pine are thinned one or more times, the final stand will contain trees more nearly uniform in size than is the case in virgin stands. When the large trees are removed in one cutting, as outlined for overmature stands, the previous thinnings will have resulted in more or less reproduction, which, together with the seed from cones on the ground and from small trees left standing, will furnish the basis for the next stand. If the large trees are removed in two or three cuttings, reproduction will be secured by the shelterwood system.

Thinnings pay well for themselves in accessible areas near Butte. From 1 acre on which there was a 60-year stand consisting of 2,044 poles, from 25 to 45 feet tall, 1,022 lagging poles were cut. Four hundred and eighty-four (about 3 per square rod) of the largest and most thrifty trees, varying from 4 to 6 inches in diameter and from 35 to 45 feet tall, were left. In addition, there were also left 538 suppressed trees too small to interfere with the growth of the larger ones. This thinning yielded $30.66 per acre in stumpage, and the trees which were left are now splendidly placed to grow rapidly to large size.

Wherever a mature or overmature stand is accessible, and the cost of removing the timber is not great, it is advisable to cut more lightly than indicated by the marking rules, in order that defective and deteriorating trees may be removed and growth stimulated over the largest possible area. Where the timber is more or less inaccessible, however, as is usually the case with lodgepole pine, it is necessary to cut heavily in order to justify the expense of the necessary improvements.

CUTTINGS ON OTHER NATIONAL FORESTS.

In a selection cutting of lodgepole pine on the Medicine Bow National Forest 36 per cent of the original board-foot volume of the stand was removed. In a similar cutting on the Arapahoe National Forest 40 per cent of the original volume was taken. The marking in these cases was considerably lighter than at French Gulch, due to the greater exposure of the timber on the Medicine Bow and to the greater accessibility of that on the Arapahoe. The marking on 22 representative acres on the Bighorn National Forest in Wyoming, in the summer of 1913 provided for the removal of approximately 58.5 per cent of the board-foot volume. Table 15 shows by diameter classes the number of trees and the volume in board feet removed and left on an average acre in the operations on the Medicine Bow National Forest.

TABLE 16.—*Number of trees and volume in board feet removed and left on an average acre in selection cuttings on the Medicine Bow National Forest, Wyo.*

[Based on 97 measured acres.]

Diameter breast high.	Trees cut per acre.				Trees left per acre.	
	Living.		Dead.		Living.	
	Number.	Volume.	Number.	Volume.	Number.	Volume.
Inches.		*Board ft.*		*Board ft.*		*Board ft.*
7	0.71	9	2.18	26	38.70	464
8	.94	23	2.19	55	37.50	932
9	1.50	63	1.54	65	31.05	1,304
10	3.03	194	1.61	103	23.95	1,531
11	2.70	230	1.27	108	15.44	1,312
12	6.76	710	.89	93	9.60	1,007
13	5.36	705	.77	98	6.47	821
14	5.04	776	.38	59	4.71	726
15	2.53	462	.29	53	2.27	412
16	2.10	439	.11	24	1.49	312
17	1.14	275	.20	47	.75	181
18	.74	205	.05	14	.37	102
19	.41	127	.05	16	.14	44
20	.21	70	.05	11	.06	21
21	.06	24	.01	4	.06	24
22	.07	31			.04	18
23	.03	15	.01	5		
24	.01	5			.03	16
25	.04	23				
26	.01	6			.01	6
28					.01	7
30	.01	8				
31	.01	9				
34	.01	12				
Total..	33.62	4,421	11.58	781	172.45	9,240

BRUSH DISPOSAL.

The object of brush disposal is to leave the cutover area in the best condition to insure reproduction and to protect it from fire and fungi. Brush left scattered haphazard over an area will permit of abundant reproduction, except where the débris is especially deep. Brush piled in windrows prevents reproduction upon the spaces they cover, though reproduction will be secured in the spaces between

FIG. 1.—BURNING A LODGEPOLE-PINE BRUSH PILE UNDER 2 FEET OF SNOW.

FIG. 2.—A BRUSH PILE LIKE THIS WILL LIGHT EASILY AND BURN CLEAN UNDER 25 OR 30 INCHES OF SNOW WITHOUT DAMAGE TO THE REMAINING TREES.

FIG. 1.—CLEAN CUTTING OF LODGEPOLE PINE (FOREGROUND) WITH COMPLETE UTILIZATION TO ABOUT 2 INCHES IN THE TOPS FOR STULLS, MINE PROPS, CONVERTER POLES, AND CORDWOOD.

Note seed strips in background.

FIG. 2.—COMPLETE UTILIZATION OF LODGEPOLE PINE ON A CLEAN-CUT AREA.

Brush pile in center of picture is 12 feet high. Such a pile can be burned in any weather.

FIG. 1.—DENSE STAND OF LODGEPOLE PINE, ABOUT 120 YEARS OLD.

Originally with 1,052 green trees per acre, nearly all under 7 inches in diameter, thinned by the removal of 260 converter poles and 300 lagging poles per acre. The thinning is probably too light to greatly benefit the remaining stand. Heavy thinning brings danger from windfalls.

FIG. 2.—STAND OF LODGEPOLE PINE, ABOUT 120 YEARS OLD.

Six thousand five hundred green trees per acre, badly in need of thinning.

the rows from the seeds from cones remaining on the ground. The same thing is true of brush left in conical piles. To secure reproduction, however, it is not necessary to leave brush piles on the ground; also, such a course is seldom, if ever, necessary in order to prevent erosion. From the standpoint of fire protection it is desirable to burn the brush in practically every case.

Burning brush scattered broadcast exposes the mineral soil. With full sunlight and the opening of sealed cones on the ground, a fairly dense stand of reproduction will be obtained in such cases, although not nearly so dense as that which comes up after a ground fire has killed standing timber, since in the latter case a greater amount of seed is preserved from destruction in the crowns of the trees. Burning an entire area on which the brush has been piled in windrows will result in a moderately dense reproduction between the rows, but no reproduction in the spaces occupied by them. When conical piles are burned the spaces occupied do not immediately come up to young growth.

The foregoing is true of clean-cut areas. Where a part of the stand is left the chances of reproduction are still better. Piling the brush in conical piles and burning it does the least damage to the remaining green trees and reproduction. Moreover, the least amount of mineral soil is exposed, thus avoiding possible over-dense reproduction following seeding from above.

Any considerable amount of brush remaining on a cut-over area greatly increases the fire danger in the remaining stand and for any reproduction which may start. Owing to the very slow decay of brush in the lodgepole-pine region the fire menace continues for a long time if the brush is left unburned. Timber operators familiar with conditions in the lodgepole-pine region say that it costs no more to pile brush for burning under Forest Service regulations than to follow the old method of piling it in windrows, provided the work is well done at the outset. When the brush is not piled properly in the first place it becomes necessary to repile it, which naturally increases the cost. Recently timber operators on the Deerlodge National Forest have been required to burn the brush as the cutting proceeds, whenever weather conditions make it safe to do so. This period of safety covers from seven to nine months in the year. Brush from stull trees is disposed of as fast as the cutting proceeds in any depth of snow encountered in the region, which at times may amount to 6 or 7 feet. In the spring when the snow melts the ground is found to be practically clean. When lagging poles are being cut in snow, however, it is not practicable to burn the tops after the snow accumulates to a depth of about 3 feet, since it is then impossible to carry the tops to the central fire. Even when the snow is less than 3 feet deep it is not advisable to burn where less than 100 poles are being obtained in one place, since there is not enough brush to start a good

fire. Data obtained in actual woods work show that piling brush in winter without burning it costs 69 cents per thousand board feet. With this method, however, the brush must always be repiled when the snow goes off in the spring. Burning as the cutting proceeds costs 74 cents per thousand, but is really cheaper than the other method because it saves the cost of repiling and of burning the following fall, and reduces the cost of skidding.

In summer cutting, brush is gathered in large piles on the clean-cut areas, and in smaller piles in the selection cuttings. Even in the latter case the piles are usually made at least 5 or 6 feet high, with a comparatively narrow base to permit them to shed rain and snow. A small brush pile can only be lighted in the fall if weather conditions are right. In the fall of 1911 the first snowfall on the Deerlodge National Forest occurred in early October, covering the ground to a depth of from 25 to 30 inches, and making it quite impossible to burn small piles. Piles of standard size, however, were lighted without difficulty. On the French Gulch sale the lighting of such piles under approximately 30 inches of snow cost about 6 cents per thousand feet. Another difficulty with small piles is the large number which have to be lighted—a circumstance which naturally tends to increase the cost.

At one time it was the practice to fork into the fire the ends of sticks and other projecting pieces left in the ring at the outer edge of the pile after the fire had burned down. With proper piling, however, only a small amount of such material should remain—not enough to constitute a fire menace. For this reason it is unnecessary to incur the comparatively large expense of having a second crew follow the lighters to fork in the unburned ends. In selection cuttings, large piles of brush can be burned within from 5 to 6 feet of green trees, provided such piles are covered with a good depth of snow. If there is room, however, piles are always built at a greater distance than this from the remaining timber. On the whole, it has been found that fall is the best time to burn brush, though weather conditions in the spring may occasionally be favorable. In the spring of 1912, for example, about 600 acres of old brush on clean-cut areas, at French Gulch, were burned at a cost of 2 cents per thousand feet.

On the Bighorn National Forest, in Wyoming, where selection cuttings have been the rule, the ideal brush pile is considered to be one about 8 feet in diameter at the base and about 5 feet high. The piles are built tepee fashion, with the larger sticks of unmerchantable material stacked up around the outside. With a cut averaging 6,700 board feet per acre, the number of brush piles per acre averaged about 40. In 1910 an area of 1,500 acres was burned on the Bighorn Forest at a cost of 6.9 cents per thousand feet; the next year 3,700 acres were burned at a cost of 3.8 cents per thousand; and in 1911, 4,200 acres were handled at a cost of 3.6 cents per

thousand. The cost varied with the number of brush piles per acre and the depth of the snow. It was found that on an average one man could in one day burn 536 piles under 8 inches of snow, 418 under 10 inches of snow, and 299 piles under 12 inches of snow.

REGULATING THE CUT.

In the existing unmanaged stands of lodgepole pine the arrangement of age classes is never ideal, and a long series of carefully planned cuttings is necessary to convert the irregular forest into a regular or normal one. Certain age classes usually occupy much more than their share of the ground, while one or more classes may be entirely lacking. For this reason the first cuttings in such a stand are, as a rule, based primarily on volume rather than on area. An estimate is made of the actual amount of growing stock on the ground and also of the probable yield during certain periods—usually 10 years—throughout the length of the rotation by the various age classes represented. With these figures as a basis, it is possible to fix the volume which can be cut during each period without exceeding the amount of wood produced. If, through the presence of large bodies of mature and overmature timber, the growing stock is greater than normal, the surplus should be removed by cutting for a few years more than is being produced; while, if through the presence of large bodies of younger age classes, the growing stock is less than normal, the deficiency should be made up by cutting for a time less than is being produced.

The management planned for the timber on the Bernice division of the Deerlodge National Forest furnishes a concrete example of the method of regulating the annual cut during the course of the next rotation. Table 16, which is based on figures secured by an estimating crew which gridironed the area in lines at intervals of one-fourth mile, shows the different classes of timbered and untimbered land on the Bernice division. Table 17 shows the degree of normality, volume, and annual increment of the different age classes found in the timbered area of the division, and Table 18 shows the proposed method of cutting for the next 140 years.

TABLE 17.—*Classification of the land and timberland on the Bernice division, Deerlodge National Forest, Mont.*

LAND.

	Area.	Per cent.
	Acres.	
Timberland [1]	63,051	80.0
Grass land	12,563	15.9
Brush land	912	1.2
Cultivated land	674	.9
Barren land	1,569	2.0
Total	78,769	100.0

[1] 62,491 acres, or 99.1 per cent, productive; 560 acres, or 0.9 per cent, alpine.

TABLE 17.—*Classification of the land and timberland on the Bernice division, Deerlodge National Forest, Mont.*—Continued.

PRODUCTIVE TIMBERLAND.

	Area and yield.	Per cent.	Area.	Per cent.
	Acres.		*Acres.*	
Merchantable	....	....	17,761	28.5
Age classes—				
Over 200 years	474	2.7		
160–200 years	2,844	16.0		
120–160 years	14,443	81.3		
Total	17,761	100.0		
Types—				
Lodgepole pine	16,080	90.6		
Douglas fir	1,526	8.6		
Engelmann spruce	155	0.8		
Total	17,761	100.0		
Stand by species—	*1,000 b. f.*			
Lodgepole pine	74,583	80.4		
Douglas fir	9,850	10.6		
Engelmann spruce	7,051	7.5		
Miscellaneous	1,347	1.5		
Total green	92,831	100.0		
Dead	8,749	....		
	Acres.			
Immature	....	....	40,585	64.9
Age classes—				
10 years	1,570	3.9		
20 years	9,742	24.0		
30 years	5,511	13.6		
40 years	7,559	18.6		
50 years	1,412	3.5		
60 years	4,887	12.0		
70 years	1,928	4.8		
80 years	2,448	6.0		
90 years	2,092	5.1		
100 years	3,040	7.5		
110 years	396	1.0		
Total	40,585	100.0		
Suppressed	....	....	4,145	6.6
Total	....	....	62,491	100.0

TABLE 18.—*Real and normal growing stock and periodic annual increment on the Bernice division, Deerlodge National Forest, Mont.*

Age.	Area.	Normality.	Growing stock.		Periodic annual increment.		Yield at the age of 140 years.[1]
			Real.	Normal.	Real.	Normal.	
	Acres.		*1,000 cu. ft.*	*1,000 cu. ft.*	*1,000 cu. ft.*	*1,000 cu. ft.*	*1,000 bd. ft.*
10 years	1,570	0.67	95	402	9	40	16,662
20 years	9,742	.69	1,815	1,205	121	80	106,476
30 years	5,511	.73	2,293	2,544	121	134	63,448
40 years	7,559	.66	5,687	5,089	284	254	78,920
50 years	1,412	.67	1,731	8,168	65	308	15,058
60 years	4,887	.49	5,747	10,713	136	254	38,090
70 years	1,928	.40	2,267	13,123	42	241	12,215
80 years	2,448	.30	2,468	14,998	31	187	11,633
90 years	2,092	.20	1,582	16,872	18	187	6,628
100 years	3,040	.20	2,481	18,211	18	134	9,631
110 years	396	.20	342	19,283	2	107	1,254
Over 120 (average age 130 years):							
Merchantable	17,761	.35	28,671	61,062	57	147	....
Suppressed	4,145	.10	1,890	....	....	....	....
Total	62,491	....	57,069	171,670	904	2,073	....

[1] Normal yield, 15,840 board feet at 140 years on sites of average quality; 78.7 per cent of area overstocked; 20.5 per cent of area understocked; 0.8 per cent of area normally stocked.

TABLE 19.—*Volume regulation for the next 140 years on the Bernice division, Deerlodge National Forest, Mont.*

Period.	Stand maturing.	Cutting each decade.	Balance at end of decade.
	1,000 b. ft.	*1,000 b. ft.*	*1,000 b. ft.*
Present (1910)	92,831	20,000	72,831
Decade beginning—			
1920		20,000	52,831
1930	[1] 28,770	20,000	61,601
1940	1,254	20,000	42,855
1950	9,631	20,000	32,486
1960	6,628	20,000	19,114
1970	11,633	20,000	10,747
1980	12,215	20,000	2,962
1990	38,090	20,000	21,052
2000	15,058	20,000	16,110
2010	78,920	70,000	25,030
2020	63,448	70,000	18,478
2030	106,730	70,000	55,208
2040	16,678	70,000	1,886
Total	481,886	480,000	1,886

Average annual yield for rotation, 3,442 thousand board feet for the division, or 55 board feet per acre of productive timberland.

[1] Increment taking place on stands now merchantable, but which will not all be cut for about 50 years (65 board feet per acre added annually on 17,761 acres for 25 years). Sixty-five board feet per acre per annum is approximately the average increment in a stand 0.6 normal on an average site between the age of 120 and 160 years.

It will be observed (Table 17) that a large proportion of the area is taken up with the younger age classes, due partly to heavy cuttings in the last 30 years. On the whole, however, the age classes are fairly well distributed for an unmanaged forest. It will also be seen (Table 18) that none of the older age classes have a high normality. This is because when such stands include over 2,000 board feet per acre they are classed with the merchantable timber, although they may be actually less than 120 years old. The method of volume regulation (Table 19) calls for a moderate cut on the division for 100 years and a much heavier one for the last 40 years of the rotation, without reducing the annual cut at any time. Such a regulation is made necessary by the irregularity in the distribution of age classes. Other divisions of the Forest have a surplus of their area in the older age classes, so that the annual cut for the entire Forest and for the whole rotation can be given the proper degree of uniformity only by applying the regulation to groups of such divisions rather than to each division separately. The figures showing the stand maturing for each 10-year period are taken directly from Table 18, except the figures for 1930, which represent the approximate growth on the mature timber originally on the area. The figures for the real growing stock (present total stand) in Table 18 were obtained by multiplying the normal stand per acre for each age class, as given in Table 9, United States Department of Agriculture Bulletin 154, "The Life History of Lodgepole Pine in the Rocky Mountains," by the average normality (which gave the present stand per acre) and multiplying this result by the actual area occupied by each age class. For example, the normal yield on average sites at 10 years of age is

90 cubic feet, the average normality of the 10-year age class is 0.67, and the actual area occupied is 1,570 acres; consequently, the real growing stock is $90 \times 0.67 \times 1{,}570 = 94{,}671$ cubic feet. The real periodic annual increment is determined by multiplying the normal periodic increment per acre, as given in Table 9, United States Department of Agriculture Bulletin 154, by the normality and by the area actually occupied. Thus, for the 10-year age class the real periodic increment is $9 \times 0.67 \times 1{,}570 = 9{,}467$ cubic feet.

The normal growing stock is based on the assumption that the forest will be managed on a 140-year rotation, and that in a normal forest each age class should have the same area. This normal area is found by dividing the total area by the number of age classes. Thus: $\frac{62491}{14} = 4{,}463.6$ acres. The normal growing stock on this area is then found by multiplying the normal yield at any given age (as given in Table 9, United States Department of Agriculture Bulletin 154) by the normal area. For example, the normal yield at 10 years of age is 90 cubic feet and the normal area of a 10-year age class is 4,463.6 acres; consequently, the normal growing stock is $90 \times 4{,}463.6 = 401{,}724$ cubic feet. Similarly, the normal periodic annual increment is the normal increment per acre (as given in Table 9, United States Department of Agriculture Bulletin 154) multiplied by the normal area.

The fact that all ages of merchantable timber were lumped together in the estimates and that, as already stated, any stand running 2,000 or more board feet per acre was considered merchantable, necessarily results in a comparatively large area and growing stock being assigned to the 120 to 160 age classes and a correspondingly small area and low normality to the age classes just under 120 years. For this reason the figures for volume increase tend to be conservative. Other reasons why these figures are conservative are that no consideration is given to the effect of future thinnings in young stands, to reproduction in old stands, or to increased growth resulting from selection cutting. Moreover, certain areas less than 0.3 normal are classed as grassland, although they bear an open stand of timber which will actually figure in the final yield. Also, rather open stands of low normality will become better stocked through the filling in of blanks. On the other hand, there will undoubtedly be some losses from fire and other causes.

It will be noticed that the scheme of regulation is presented as though the area would be managed under a clear-cutting system, though actually the cutting will be done largely under a selection system. The reason for this is that it is possible to figure much more readily for a clear-cutting than for a selection system, while, in any event, the main object is to obtain a fairly conservative estimate of the probable volume production, which is likely to be as great under the selection system as another.

Within the 25 National Forests in which lodgepole pine is the most important species the lodgepole-pine type has an estimated area of about 9,000,000 acres. The figures for the Deerlodge National Forest show an average annual increment of about 55 board feet. Assuming that the lodgepole-pine forests throughout the region are producing 50 board feet per acre per annum, 450,000,000 board feet could and should be cut annually, together with a very large amount of material from tops, small trees, and thinnings too small to scale. To this amount can be added about 300,000,000 board feet produced on the 6,000,000 acres of lodgepole-pine type in the 45 National Forests where the species is of commercial but not of primary importance. The grand total of 750,000,000 board feet is approximately 9 times the amount of lodgepole pine now being cut each year.

REFORESTATION.

Repeated fires have left considerable areas within the lodgepole-pine zone practically barren of forest growth. Natural reproduction can not be expected on such areas for many years, and it will be necessary to reforest them artificially if they are to return to usefulness within a reasonable length of time. Where the main object is watershed protection, reforestation work should be confined chiefly to the higher altitudes toward the upper limit of the lodgepole-pine zone, where the forest cover has the greatest protective value. Where the chief object is timber production, the best results will be obtained on the better soils near the central part of the lodgepole-pine zone where the annual precipitation is 21 inches or more. A certain amount of artificial reforestation will also probably be used in the future to supplement natural reproduction after cuttings.

SEED COLLECTION AND EXTRACTION.

The fact that lodgepole pine bears some cones practically every year and a heavy crop every two or three years insures a continuous and plentiful seed supply. The cones may be picked either from felled or from standing trees, or gathered from squirrel hoards. Experience, however, has shown the last method to be the only one by which collecting can be done on a large scale at low cost. Cone collection from squirrel hoards is carried on in the fall, usually during September and October, when the caches are full and easily located in the woods. As much as 15 bushels of cones have been found in a single cache. Cones can usually be bought at contract prices per bushel from local residents who do the collecting. As a rule, one man collects from 3 to 6 bushels per day, the number of cones per bushel ranging from about 1,600 to 2,200. In good years it should be possible to purchase cones for from 30 to 40 cents per bushel, or in exceptionally favorable years for even less. The total cost of cones at the extraction plant should not exceed 50 cents per bushel.

Lodgepole-pine seed is hard to extract from the cones, and a drying temperature of from 140° to 150° F. is necessary before the latter will open satisfactorily. During the process of drying there must, of course, be enough air circulation to remove the moisture given off by the cones. Where only a few hundred bushels of cones are to be handled, any small room, provided it can be made tight, will serve as a dry kiln. Trays with wire-mesh bottoms, on which the cones are spread in a single layer, should be arranged in tiers, so as fully to utilize the available space. Eight hours of drying at a temperature of from 140° to 150° should open the cones to the extent necessary. Hourly thermometer readings should be taken, in order to insure that the proper temperature is maintained. One higher than 150° may injure the seed, while one lower than 140° will not open the cones. Provision must also be made for removing the moist air from the kiln. The latter should be run continuously day and night, since if it is operated intermittently the cost of extraction will be increased. Wherever the cones can be stored in bins with a free circulation of air, it is usually best to defer seed extraction until late in the winter. After two or three months in such bins the cones will have lost a large percentage of moisture merely through natural air drying.

After the cones have been opened in the drying kiln they must be shaken or thrashed out in order to extract the seed. This is done by means of a cone shaker, which consists merely of a revolving box or drum with a wire covering, through which the extracted seeds fall to the ground. The wings can then be removed by sacking the seed loosely and giving it a vigorous kneading. Where a large quantity of seed is handled a cheaper method is to moisten it slightly and rub it through a wire screen with an ordinary scrubbing brush. After being freed of their wings the seeds are dried again. The cleaning of the seed is finally completed either by winnowing it or by running it through a fanning mill fitted with screens of proper mesh in order to remove all foreign matter, such as pine needles, cone scales, broken wings, and dirt.

It is usually cheaper to extract and clean seed in the immediate vicinity of the area where the cones are gathered than to transport quantities of the bulky cones to a central seed-extraction plant. When seed is to be cleaned regularly in large quantities, however, specially constructed drying kilns are best and cheapest in the long run. A number of such permanent seed-extraction plants have been constructed on the National Forests. These include several small plants, with a capacity of about 90 bushels of cones per 24-hour running, and one large plant capable of handling about 200 bushels in 24 hours. In the latter, located on the Medicine Bow National Forest, a hot-air blast is forced through a large, slowly revolving cylinder, so that the cones are dried and the seed extracted at the

same time. The wings are removed and the seed cleaned by machinery. All the plants are located in extensive longepole-pine forests, where a large supply of cheap cones is constantly available.

The cost of extraction varies with the quantity of seed handled, the abundance of the cone crop, and the efficiency of the methods used. In 1911 the total cost of cleaned seed on the Arapaho and Medicine Bow National Forests, the two Forests which handle the largest amounts, was $1.98 and $2.28 per pound, respectively, against $3.82 and $4.27 per pound, respectively, in 1910. In 1912 the cost of cleaned seed on these Forests amounted, respectively, to $1.80 and $2 per pound. In the three States of Colorado, Wyoming, and Montana 2,560 pounds of lodgepole-pine seed were cleaned in 1910, at an average cost of $4.94 per pound, and 3,350 pounds in 1911, at an average cost of $2.76 per pound. This decrease in average cost was due largely to the concentration of the collecting work in a few places. With improved methods of collecting, extracting, and cleaning lodgepole-pine seed can probably be obtained in the future for less than $2 per pound.

TABLE 20.—*Results of germination tests on lodgepole-pine seed collected from National Forests in the Rocky Mountains.*

National Forest.	Germination.		Real value (number of fertile seed per pound).[1]	National Forest.	Germination.		Real value (number of fertile seed per pound).[1]
	Number of days.	Per cent.			Number of days.	Per cent.	
Collected 1910:				Collected 1911—Con.			
Holy Cross	94	80.5	98,700	Shoshone	27	55.2	50,849
Gunnison	90	71.5	65,000		27	48.6	41,030
Leadville	90	76.5	81,700	Collected 1912:			
Shoshone	89	78.0	68,000	Wyoming	43	23.5	16,920
Arapaho	86	67.0	65,700	Arapaho	31	61.4	63,920
Bonneville	44	33.5	33,100	Do	31	52.0	46,040
Collected 1911:					31	55.2	55,970
Wyoming	25	65.0	51,522		31	55.4	57,759
Arapaho	27	74.6	66,793	Leadville	31	52.8	59,084
	27	36.8	17,644		31	65.6	68,100
Hayden	27	82.2	49,887		31	58.4	61,600
	27	24.6	21,981		31	61.0	66,200
Leadville	27	43.8	43,536	Medicine Bow	31	67.4	67,150
	27	76.6	71,661		31	71.6	67,200
Medicine Bow	27	66.6	63,404		31	59.2	54,560
	27	24.2	23,355		31	58.0	47,250
Routt	27	68.8	56,485				

[1] Obtained by multiplying the total number of seed per pound by the germination per cent.

Lodgepole-pine seed collected in different localities, under different conditions, shows wide variation in its capacity to germinate, as shown in Table 19. For this reason every lot of seed before being used in the field or in the nursery should be tested to determine the number of fertile seed per pound. The seed collected in 1911 was tested only for a period of 27 days, since experiments had shown that by far the greater amount of germination occurred within this time.[1]

[1] The germination per cent obtained from a limited test of this sort is often called "germination energy," as distinguished from "germinative capacity," the latter being the germination per cent secured when the test is allowed to run for a much longer period.

A test limited to a certain number of days is not only much cheaper than a longer one, but gives figures of more practical value in actual sowing operations either in the nursery or in the field. This is because the figures for short tests are based on the behavior of the more vigorous, active seeds, which may be counted on to germinate early under soil conditions perhaps not favorable enough to induce germination of the more sluggish seeds in any reasonable period of time.

DIRECT SEEDING.

Direct seeding is the simplest method of reforestation, and can be used wherever conditions are such as to make it practicable. It is far less certain of success than planting, however, and should be used only on the most favorable sites. Good germination is often difficult to secure, and there is always the likelihood that the seed will be eaten by rodents. Moreover, the young seedlings which come up are exposed to damage from drought during the first growing season and to winterkilling during the first winter. Areas best adapted to direct seeding with lodgepole pine are those where a large proportion of the mineral soil is exposed. This condition is seldom found, however, outside of burns not more than 2 or 3 years old. As a general thing, areas in need of reforestation bear a more or less heavy covering of grass, herbs, and shrubs. Such a cover, particularly when it takes the form of a dense sod, is a serious obstacle to direct seeding, since it prevents seeds from reaching the mineral soil, and after germination competes with the seedlings for the available moisture. The shade cast by a light covering of shrubs or trees, on the other hand, may be beneficial to young lodgepole-pine seedlings by preventing the surface soil from drying out. An open stand of aspen affords an excellent shelter, provided it is not so dense as to interfere with the thrifty development of the seedlings after their establishment. The less favorable the moisture conditions, the greater, of course, is the need for some sort of ground cover.

The season for sowing, while of less importance than either the site or the method, nevertheless has considerable influence on the result. The seed should be sown at a time to insure that the maximum amount of moisture will be available for the young seedlings immediately upon their appearance. At the lower and drier altitudes the best time for sowing is either in the fall (September or October) or in the winter on the snow. At the higher altitudes the best time is either in the winter or in late spring or early summer (May or early June). Experiments by the Forest Service covering a wide range of methods indicate the best to be seeding in prepared spots and broadcasting on snow. The spots are usually spaced from 4 to 6 feet apart each way, requiring from one-half to 1 pound of seed per acre. Broadcasting on snow is practicable only on very

recent burns or on other areas where the seed can easily reach the mineral soil. In such cases, sowing should be done in late winter or early spring, when the surface of the snow is thawing and the seed will sink in, and preferably at a time when there is a likelihood of another fall of snow. When the snow finally leaves the area, the seed is washed into the soil, and conditions are favorable for early germination. The seed is usually broadcasted at the rate of two fertile seeds per square foot, equivalent to from 2 to 3 pounds of seed per acre.

Every area broadcasted with seed must be protected from rodents, such as squirrels and field mice, until after the seed has germinated. Many of the early failures in reforestation were due to the depredations of small rodents that devoured the seed as quickly as it was sown. For this reason every seeded area should be poisoned as a measure of protection.[1] This should be done several weeks before the seed is sown, and preferably again after it is in the ground. The seeded areas should also be protected against the grazing of livestock, and, after the small seedlings appear, against fire.

In 1910, 630 acres in the three States of Colorado, Wyoming, and Montana were reforested to lodgepole pine by direct seeding, at an average cost of \$10.77 per acre. In 1911, 640 acres in these States were seeded at an average cost of \$8.68 per acre. These costs are abnormally high, since much of the work was experimental, and in many cases unnecessarily large amounts of seed were used. Under ordinary conditions it should be possible to carry on direct seeding by the two methods described within the following limits of cost:

	Cost per acre.	
	Seed spots.	Broadcasting.
Seed (at \$2 per pound)	\$1.00 to \$2.00	\$4.00 to \$6.00
Seed sowing	2.50 4.50	.25 .75
Poisoning rodents	.10 .15	.10 15
Total	3.60 6.65	4.35 6.90

Where the area to be seeded is very rough and steep, or is covered with fallen timber or bowlders, the maximum costs just given may sometimes be exceeded. In many cases, also, it will be necessary to reseed certain portions of the area in order to secure a satisfactory stand. Fail spots should not be reseeded, however, until two or three years after the first sowing, since a portion of the original seed often lies over for a year before germination.

[1] Information regarding the best methods of poisoning rodents is contained in Forest Service Bulletin 98, "Reforestation on the National Forests"; Bureau of the Biological Survey Circular 78, "Seed Eating Mammals in Relation to Reforestation"; and Farmers' Bulletin 484, "Some Common Mammals of Western Montana in Relation to Agriculture and Spotted Fever."

TABLE 21.—*Results of direct seeding of lodgepole pine by various methods in National Forests in Colorado and Montana.*

National Forest.	Acres sown.	Site. Elevation.	Site. Character.	Method of sowing.	Protection against rodents.	Date of sowing.	Results. Average stand of seedlings.	Results. Date counted.
		Feet.					*Number per acre.*	
Arapaho	0.90	9,900	Recent burn, mineral soil exposed	Seed spots	Poisoned	June, 1911	13,050	July, 1913
	12.00	9,900	do	Broadcast on snow	None	May, 1911	2,000	Do.
	51.70	9,000	14-year-old burn, aspen cover	do	do	April 15, 1912	1,767	June, 1913
	78.00	9,500	do	do	do	April 16, 1912	2,250	Do.
	30.00	9,000	do	do	do	April 11, 1912	5,200	Do.
	20.06	9,000	do	Seed spots	do	June, 1912	3,500	Do.
	24.90	9,600	Cut over 4 years ago	Broadcast on snow	do	April 24–25, 1912	1,350	Do.
Colorado	34.00	9,400	Old burn, heavy ground cover	Broadcast on ground	Poisoned, 1910.	Spring 1910 and 1911	2,000	July, 1913
	21.33	9,200	Old burn, grass and weeds	Seed spots	Poisoned	September, 1912	1,540	Do.
	10.00	10,000	Old burn, scattering grass	do	do	June, 1912	2,100	Do.
	20.00	10,000	do	do	do	do	861	Do.
	40.00	9,600	Grass, etc	Broadcast on ground	do	May, 1912	2,838	August, 1912
Durango	2.00	8,000	Yellow pine type, heavy oak brush	Seed spots	do	November, 1910		July, 1912
Gunnison	.20	9,600	Old burn, mineral soil exposed	do	do	June, 1911	2,596	Sept., 1912
Leadville	22.00	9,800	Very old burn, light aspen cover	do	do	November, 1910	1,130	June, 1913
	10.00	9,500	Old burn, aspen cover	do	do	May, 1912	180	July, 1913
	50.50	10,000	do	do	do	do	370	Do.
	50.00	9,500	do	do	do	do	560	Do.
Absaroka	50.00	7,000	Clay loam	Broadcast on ground	None	March, 1911	350	May, 1913
Beartooth	2.60	7,200	do	Corn planter	Poisoned	May, 1911	0	Sept., 1912
	4.75	7,000	Gravelly loam	Broadcast on ground	do	do	20	May, 1912
	12.12	7,500	do	do	do	November, 1911	0	July, 1912
	15.00	7,200	Sandy loam	Corn planter	do	May, 1912	0	
Beaverhead	5.00	7,000	Gravelly loam	Seed spots	do	April, 1911	0	May, 1912
	23.00	7,000	do	Corn planter	do	do	0	Do.
	43.00	7,000	do	Broadcast on snow	do	do	0	Do.
	13.00	7,000	Limestone gravel loam	Seed spots	do	do	0	Do.
Madison	50.00	6,500	Gravelly loam	Broadcast on snow	Seed coated with red lead.	March, 1911	0	Do.

Table 21 shows the result of direct seeding on some of the National forests in Colorado and Montana. It will be seen that in the former State the direct seeding of lodgepole pine has been attended with a fair degree of success, while in the latter it has been practically a total failure. It is not easy to account for this difference, though it seems that the greater rainfall of Colorado has had its effect. Though enough reforestation work has not yet been done to demonstrate conclusively the possibilities of direct seeding, it seems certain that in Montana a more satisfactory stand can be secured at less cost by setting out plants raised in a nursery than by sowing seed directly on the site, while in Colorado, on the other hand, direct seeding should give the best results, provided conditions are favorable. Under adverse conditions, of course, reforestation by direct seeding can not be expected to prove successful even in Colorado.

PLANTING.

While comparatively little lodgepole pine has been planted, the experiments conducted by the Forest Service prove pretty conclusively that this method of reforestation will be successful. If grown on a large scale, 3-year-old transplants can be raised at a cost of from $3 to $5 per thousand. Field planting at the rate of 1,000 to the acre costs from $6 to $8 per thousand, making the total cost per acre from $9 to $13. This is considerably more than the cost of direct seeding where the latter is successful the first time, yet so few sites are fitted for seeding that planting will in most places cost less in the long run. If the ground has to be seeded several times to obtain a satisfactory stand, planting will have a great advantage in cost.

One obstacle to artificial reforestation with lodgepole pine is the tree's slow rate of growth. This means that interest charges on the original investment must be carried for a long time, and also that yield is comparatively small. Lodgepole pine will yield about 10,900 board feet of timber per acre in 100 years, worth $4 per thousand. With a cost for planting of $9 per acre and a charge of 5 cents per acre per year for fire protection, a planted stand of lodgepole pine will yield only 1¼ per cent on the money invested. Western white pine, on the other hand, with a cost for planting of $7 per acre and a charge of 10 cents per acre per year, yields 75,000 board feet per acre in 100 years, worth $5 per thousand, or a return of 6¼ per cent on the money invested. With the rotation of 140 years which would ordinarily be required for lodgepole pine, the comparison would be still more unfavorable to it. Lodgepole pine will hardly be planted on a large scale until large areas of more productive sites have been reported.

Where it is desired to reestablish the forests over a large area at the lowest cost, small groups of 5 or 6 trees may be planted, the groups 40 or 50 feet apart. Such groups could be counted on to begin the reseeding of the remainder of the area as soon as the trees

become old enough to bear fertile seed, usually in 15 or 20 years. Planting by this method would require from 125 to 150 seedlings per acre, and should cost about $2.

PROTECTION.

FIRE.

Although fire is the principal agent in aiding lodgepole pine to maintain its existence in many places, it is also the most destructive agent in mature lodgepole-pine stands. Besides the active measures taken to prevent and extinguish fires, such as lookout stations, telephone lines, roads and trails, patrol, and the like, certain coordinate lines of forest work may be handled in a manner to insure that the fire danger will be kept at the minimum. The most important of these in the case of lodgepole pine is the grazing of live stock, particularly sheep. In the lodgepole-pine region fire almost invariably spreads by means of grass and weeds. A grass fire travels very rapidly and soon spreads over large areas. The grass of the lodgepole-pine region becomes sun-cured early in July and dries very rapidly after summer showers which dampen other inflammable material for several days. Thorough grazing on the dangerous areas by sheep would dispose of most of the inflammable material. Old grass left over from the previous year is particularly inflammable and makes a very hot fire. Particularly heavy grazing along trails, secondary ridge tops, and certain section lines would be a means of securing fire lines at frequent intervals. When grazing in the timber sheep trample and wear out the down litter and other débris, greatly hastening its decay.

In addition to the grass which grows in and near the timber, pine needles and other débris form an inflammable ground cover. A fire in needles alone travels slowly and is easily controlled. Where, however, there is also a considerable amount of débris, such as old tops and down timber under dense young stands, the heat from below sometimes starts crown fires, though this is rare in lodgepole pine. Fires on cut-over areas where the brush has been piled and burned are easy to control. Where the brush has been well piled and not burned there is danger of a hot fire which will kill many green trees near the piles. Such a fire is harder to handle, of course, than one on a cleaned-up area, but it is by no means as hard to handle as one on an area where the slash is left in windrows or scattered over the ground. Roads and skidding trails constructed in connection with cuttings and thinnings will act as fire breaks. Much less débris is likely to accumulate in the well-spaced, moderately open stands which come up after cutting than in the over-dense stands resulting from fire. By the time the lodgepole-pine region has been cut over once under Forest Service regulations, with the proper amount of grazing, the fire danger will have been very much reduced, even though no further advance is made in other means of prevention and control.

INSECTS.

Much can be done to prevent serious insect damage in lodgepole-pine stands merely by keeping the forests in the best silvicultural condition. The removal of over-mature and unhealthy trees and the thinning of overstocked stands will leave the more thrifty timber, the kind best able to resist insect attacks. When an outbreak does occur, measures of control should be taken promptly, since an insect infection can be dealt with most effectively and with least cost in its incipiency. Whenever possible the bark should be removed from attacked trees. This may be done either after the trees are felled or while they are still standing, provided the infested parts can be reached from the ground. Infested trees can frequently be sold or given away under free use, or used for administrative purposes, although in some cases it may be necessary to treat them without any prospect of their immediate utilization.

Where an insect attack is widespread, a specially organized campaign may be necessary. When the mountain pine beetle (*Dendroctonus monticolæ*) attacked the lodgepole pine in the Bighole Basin in the Deerlodge and Beaverhead National Forests in Montana, in 1912, 2,426 trees were treated in late June and in early July, of which 25 per cent, averaging 13 inches in diameter, were felled and peeled for a distance of about 24 feet from the stump. The cost of this work, including brush disposal, amounted to about $1.75 per tree. The remainder of the trees, averaging 11 inches in diameter, were peeled as they stood to a height of about 8 feet from the ground, at a cost of 39 cents per tree. Trees as small as 6 inches in diameter were infested, but no trees less than 8 inches in diameter were treated. The costs in this case were excessively high, owing to the very short time in which the work could be done, the lack of suitable tools, and to several changes in plan. In 1913, during the 45 days following May 21, a total of 23,393 trees, averaging 12 inches in diameter and standing on an area of 60,000 acres, were peeled as they stood to an average height of 12 feet, at an average cost of 33½ cents per tree. The aim of this work was not to destroy the insects entirely, but to reduce their numbers to a point where their natural enemies, such as birds and parasites, would be able to keep them under control. It is believed that this has been accomplished. The total cost of the work during the two seasons was $9,540.67. This expenditure has rendered safe for the present an overmature stand which will almost surely bring a stumpage price of over $1,000,000 within the next 20 years, provided the timber is kept green. During 1913, in the course of a similar control project in lodgepole and yellow pine on the Ochoco National Forest in Oregon, 12,873 trees were treated at an average cost of 50 cents each, on an area of about 12,000 acres. In this case the trees were felled and peeled, and the bark burned.

DISEASES.

Little can be done to protect the lodgepole-pine forests from fungi and mistletoe, except to remove whenever practicable all diseased trees and to keep cut-over areas free from débris. Partly merchantable trees attacked with rot should be felled and the sound portions utilized. All infected trees, however, whether merchantable or not, should be felled, if possible, as a measure of protection to the remaining stand.

GRAZING.

The grazing of live stock is usually helpful in a lodgepole-pine stand as a means of reducing the fire danger. On recently cut-over areas, however, sheep grazing should be carefully regulated, if allowed at all, until reproduction is well established. Where an unusually heavy sod is an obstacle to reproduction, heavy grazing by sheep may be a means of exposing the mineral soil.

SUMMARY.

Lodgepole pine is the most important commercial species over a large part of the Rocky Mountains. It is already used for railroad ties, mine timbers, and fence posts, and in the future will no doubt be extensively employed for telephone poles and rough lumber. In addition to their commercial value, the lodgepole-pine forests are of great importance as a protective cover on the watersheds.

Overmature stands of lodgepole pine should be cut practically clean. Mature stands should be cut under the group selection system in order to prevent an overproduction of small material and to secure increased growth of the smaller trees left. In marking under this system, the aim should always be to insure against excessive windfall. Overdense young stands should be thinned whenever practicable. As a general thing, no special measures need be taken to secure reproduction. All brush on timber-sale areas should be piled and burned. Where artificial reforestation is necessary, planting will usually be the most satisfactory method, though direct seeding may give satisfactory results on exceptionally favorable sites. Protection from fire is the first step in systematic forest management.

APPENDIX.

VOLUME TABLES.

Table 22 shows the contents in board feet of trees of different diameters and containing different numbers of 16-foot logs. For trees from 7 to 9 inches in diameter, inclusive, and for all one-log trees, the table is based on 555 trees measured in Deerlodge County, Mont., with an average stump height of from 0.5 to 1 foot, and an average top diameter inside the bark of 6 inches; for all trees 10 inches and over in diameter and containing more than one 16-foot log, it is based on 1,808 trees measured in Gallatin County, Mont., with an average stump height of from 1.4 to 2.2 feet and an average top diameter inside the bark of from 6.2 to 6.6 inches.

TABLE 22.—*Average contents in board feet (Scribner Decimal C rule) of lodgepole-pine trees of various diameters and 16-foot log contents, Gallatin and Deerlodge Counties, Mont.*

Diameter breast high.	Number of 16-foot logs.					Diameter breast high.	Number of 16-foot logs.				
	1	2	3	4	5		1	2	3	4	5
	Contents in board feet.						Contents in board feet.				
Inches.						*Inches.*					
7	10	...	...	...	...	16	90	135	190	270	365
8	20	40	...	...	...	17	105	150	210	305	405
9	25	50	...	...	...	18	120	165	240	340	445
10	35	60	90	125	...	19	135	195	270	375	485
11	45	70	100	140	...	20	150	220	300	410	525
12	50	80	115	160	...	21	170	245	330	450	565
13	60	90	130	180	...	22	190	...	365	485	605
14	70	105	150	210	280	23	...	...	400	525	650
15	80	120	165	240	325	24	...	...	440	565	690

Table 23 shows the contents in cubic feet and in board feet of trees of various diameters and total heights in the Deerlodge and Gallatin National Forests, Mont. The volume in cubic feet includes the entire contents of the tree (exclusive of bark) from the top of the stump to a top diameter of from 2 to 3 inches inside the bark. The volume in board feet shows the amount of scale material included in the tree to a top diameter of 6 inches inside the bark. Besides the board-foot contents there is always a small amount of additional material in the tops which can be used for lagging poles, converter poles, cordwood, etc., when such material is marketable.

TABLE 23.—*Average contents in cubic feet, to a top diameter of from 2 to 3 inches inside bark and in board feet (Scribner Decimal C rule) to a top diameter of 6 inches inside the bark, of lodgepole pine trees of various diameters and total heights, Deerlodge and Gallatin National Forests, Mont.*

Diameter breast high.	Total height of trees in feet.															
	30		40		50		60		70		80		90		100	
Ins.	*C.ft.*	*B.ft.*	*Cu.ft.*	*B.ft.*	*Cu.ft.*	*Bd.ft.*	*Cu.ft.*	*B.ft.*	*Cu.ft.*	*Bd.ft.*	*Cu.ft.*	*Bd.ft.*	*Cu.ft.*	*Bd.ft.*	*Cu.ft.*	*Bd.ft.*
3	1.0	.....	1.3	.....	1.8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4	1.5	.....	1.7	.....	2.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	2.1	.....	3.0	.....	4.0	.....	5.4	.....	.....	.....	.....	.....	.....	.....	.....	.....
6	2.7	.....	3.3	.....	5.1	.....	6.0	.....	8.0	.....	.....	.....	.....	.....	.....	.....
7	4.0	.....	5.5	.....	7.3	10	9.6	30	11.2	40	.....	.....	.....	.....	.....	.....
8	4.8	.....	7.5	20	9.5	30	11.4	40	14.0	50	15.8	60	.....	.....	.....	.....
9	.....	.....	8.9	25	11.0	35	14.2	50	17.0	60	19.1	75	.....	.....	.....	.....
10	.....	.....	.....	.....	12.5	45	16.6	60	20.0	75	23.0	90	.....	.....	.....	.....
11	.....	.....	.....	.....	14.0	60	19.9	70	23.0	90	27.4	105	.....	.....	.....	.....
12	.....	.....	.....	.....	17.0	70	22.2	85	26.8	105	32.0	130	36.0	[illegible]	.....	.....
13	.....	.....	.....	.....	21.0	90	26.0	105	30.6	130	37.0	160	42.0	190	.....	.....
14	.....	.....	.....	.....	.....	.....	30.0	125	34.2	155	42.0	190	48.0	230	58.0	290
15	.....	.....	.....	.....	.....	.....	.....	.....	38.4	180	47.0	220	55.0	270	65.5	340
16	.....	.....	.....	.....	.....	.....	.....	.....	42.5	205	52.0	250	61.0	310	79.9	395
17	.....	.....	.....	.....	.....	.....	.....	.....	46.5	230	57.0	280	67.5	350	79.0	450
18	.....	.....	.....	.....	.....	.....	.....	.....	51.5	250	62.6	315	74.0	390	86.0	510
19	.....	.....	.....	.....	.....	.....	.....	.....	56.0	275	68.0	350	80.0	430	93.0	600
20	.....	.....	.....	.....	.....	.....	.....	.....	62.0	300	73.0	385	87.0	470	100.0	.....

Table 24 shows the contents in board feet and props of trees of various diameters on three different quality sites in the Arapaho National Forest, Colo. In applying this table to any given stand, the heights of a few trees of different diameters should be measured and compared with the heights given in the table, in order to determine the site quality of the stand being measured. If, as estimating progresses, the average height of the stand changes materially, new height measurements should be taken and the figures applicable to the new site used. This table is based on 1,275 trees cut from overmature stands (about 200 years old) of moderate density. The height of a tree of a given diameter varies with its age, while the relation between its diameter and height, and consequently between its diameter and volume, varies with the density of the stand. Height alone, moreover, does not determine site quality. For these reasons the table is applicable only to the region in which it was made and to stands similar to those in which the figures were secured. Tables based on diameter, and total height, or diameter and number of logs, have a much wider application. The present table allows 8 per cent of defect for old timber, but if unusually defective timber is encountered additional allowance must be made. The volume in board feet includes all of the tree from a stump height of 1 foot to a diameter of 6 inches in the top; the remainder of the tree down to a diameter of 5 inches in the top is given as prop material, expressed in linear feet.

TABLE 24.—*Volume of lodgepole-pine trees of various diameters in board feet (Scribner Decimal C rule) and linear feet of props on three site qualities, Arapaho National Forest, Colo.*

Diameter breast high.	Site quality I.			Site quality II.			Site quality III.		
	Board feet.	Props, linear feet.	Height of tree.	Board feet.	Props, linear feet.	Height of tree.	Board feet.	Props, linear feet.	Height of tree.
Inches.			*Feet.*			*Feet.*			*Feet.*
6	0	20	50	0	18	41	0	15	32
7	25	15	56	20	13	48	15	11	37
8	45	12	62	35	10	53	30	10	42
9	65	10	68	55	10	58	45	10	47
10	70	10	73	75	10	62	60	10	51
11	120	11	77	95	10	66	75	10	55
12	150	12	80	120	10	69	90	10	59
13	180	12	84	145	10	72	115	10	62
14	210	10	87	170	10	75	140	10	64
15	240	13	89	200	10	77	165	8	66
16	275	14	91	235	10	79	190	8	68
17	315	13	93	270	10	81	215	6	69
18	360	12	94	305	10	82	245	6	70
19	405	12	95	340	8	83	270	6	71
20	445	13	96	375	6	84	300	6	72
21	490	12	96	405	6	85	....	....	....
22	530	13	96	440	6	86	....	....	....
23	575	14	97	....	....	....	....	....	....
24	615	15	97	....	....	....	....	....	....

Table 25 is similar to Table 23, except that it represents an average stand without division into site qualities, and includes prop material to a top diameter of 4 inches.

TABLE 25.—*Volume of lodgepole-pine trees of various diameters in board feet (Scribner Decimal C rule), and in linear feet of props on average sites, Medicine Bow National Forest, Wyo.*

Diameter breast high.	Board feet.	Props, linear feet.	Diameter, breast high.	Board feet.	Props, linear feet.
Inches.			*Inches.*		
5	....	8	13	127	8
6	5	17	14	154	8
7	12	18	15	182	8
8	25	36	16	209	6
9	42	10	17	240	6
10	64	8	18	276	5
11	85	8	19	308	7
12	105	8	20	342	4

Table 26 shows the average number of ties and the amount of prop material, expressed in board feet, for trees of different diameters irrespective of height. The table is based on about 90,000 old trees cut in extensive logging operations on the Medicine Bow National Forest, and includes allowance for all defect.

TABLE 26.—*Average number of ties (7″×7″×8′) and board feet of prop material in lodgepole pine trees of various diameters, Medicine Bow National Forest, Wyo.*

Diameter, breast high.	Number of ties.	Prop material.	Diameter, breast high.	Number of ties.	Prop material.
Inches.		*Board feet.*	*Inches.*		*Board feet.*
10	1.7	13	14	3.6	13
11	2.0	14	15	4.3	12
12	2.4	14	16	4.8	11
13	3.0	14	17	5.0	10

Table 27, which is based on 894 trees, shows the number of ties (including about 25 per cent second-class ties), and of prop material expressed in linear feet, for trees from 10 to 15 inches in diameter and from 50 to 90 feet in height.

TABLE 27.[1]—*Average number of first and second class railroad ties and amount of mine prop material in lodgepole pine, Medicine Bow National Forest, Wyo.*

Diameter breast high.	Total height of trees.									
	50 feet.		60 feet.		70 feet.		80 feet.		90 feet.	
	Ties.	Props.	Ties.	Props.	Ties.	Props.	Ties.	Props.	Ties.	Props.
Inches.	*No.*	*Feet.*	*No.*	*Feet.*	*No.*	*Feet.*	*No.*	*Feet.*	*No.*	*Feet.*
10	2.0	17	2.3	21	2.5	25	3.0	29	....	....
11	2.4	13	2.7	18	3.0	21	3.6	25	4.0	28
12	2.8	12	3.2	15	3.5	19	4.1	21	4.5	24
13	3.3	11	3.6	14	4.0	17	4.7	19	4.9	21
14	3.7	11	4.0	13	4.5	15	5.1	17	5.4	19
15	4.0	11	4.4	13	5.0	14	5.5	15	5.8	17

[1] From Forest Service Circular 126.

FORM TABLES.

Table 28, based on 735 trees, shows the butt taper in trees of different sizes, and is useful for estimating the diameter breast high when only the stumps remain. While the table is based on measurements taken in Wyoming, it has been found to be reliable for Montana, and is probably so for Colorado.

TABLE 28.[1]—*Butt taper of lodgepole pine as shown by diameter outside bark, Medicine Bow National Forest, Wyo.*

Diameter breast high.	Height from ground.					Diameter breast high.	Height from ground.				
	1 foot.	2 feet.	3 feet.	4 feet.	5 feet.		1 foot.	2 feet.	3 feet.	4 feet.	5 feet.
	Diameter.						Diameter.				
Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
5	5.5	5.4	5.2	5.1	4.9	12	13.3	12.5	12.2	12.1	11.9
6	6.6	6.4	6.2	6.1	5.9	13	14.4	13.6	13.2	13.1	12.9
7	7.8	7.4	7.2	7.1	6.9	14	15.6	14.7	14.2	14.1	13.9
8	8.9	8.4	8.2	8.1	7.9	15	16.8	15.8	15.3	15.1	14.9
9	10.0	9.4	9.2	9.1	8.9	16	18.0	16.9	16.4	16.1	15.9
10	11.1	10.4	10.2	10.1	9.9	17	19.3	18.1	17.5	17.1	16.9
11	12.2	11.5	11.2	11.1	10.9						

[1] From Forest Service Circular 126.

Table 29 shows the stem taper of lodgepole-pine trees of different diameters breast high. Such a table can be used as a basis for constructing volume tables in terms of any desired unit, and is also useful as showing at what distance from the ground any given diameter occurs, in trees of different diameters and heights.

TABLE 29.—*Stem taper of lodgepole pine as shown by diameter inside bark, Gallatin and Deerlodge Counties, Mont.*[1]

TREES 50 FEET IN HEIGHT.

Diameter breast high.	Height from ground.										
	5 feet.	10 feet.	15 feet.	20 feet.	25 feet.	30 feet.	35 feet.	40 feet.	45 feet.	50 feet.	Basis.
Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Trees.*
7	6.8	6.4	5.9	5.5							8
8	7.8	7.3	6.7	6.2	5.5						8
9	8.8	8.2	7.6	6.9	6.2	5.5					7
10	9.7	9.1	8.4	7.7	7.0	6.2	5.4				
11	10.7	10.0	9.2	8.4	7.7	7.0	6.2	5.3			10
Total											33

TREES 60 FEET IN HEIGHT.

Diameter breast high.	Height from ground.										
	5 feet.	10 feet.	15 feet.	20 feet.	25 feet.	30 feet.	35 feet.	40 feet.	45 feet.	50 feet.	Basis.
Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Trees.*
7	6.8	6.6	6.4	6.0	5.7	5.2	4.6				13
8	7.8	7.5	7.2	6.8	6.4	6.0	5.5	4.7			22
9	8.8	8.4	8.0	7.6	7.2	6.6	6.0	5.3			
10	9.8	9.2	8.8	8.5	8.0	7.3	6.6	5.9			50
11	10.8	10.0	9.5	9.0	8.4	7.6	6.8	6.0	5.2	4.5	50
12	11.6	10.8	10.2	9.6	8.8	8.0	7.1	6.2	5.4	4.6	51
13	12.6	11.6	11.0	10.3	9.4	8.5	7.5	6.5	5.6	4.7	17
14	13.5	12.5	11.8	11.1	10.3	9.3	8.1	7.0	5.9	4.9	9
15	14.5	13.4	12.7	12.0	11.1	10.0	8.8	7.5	6.3	5.1	9
Total											221

TREES 70 FEET IN HEIGHT.

Diameter breast high.	Height from ground.												
	5 feet.	10 feet.	15 feet.	20 feet.	25 feet.	30 feet.	35 feet.	40 feet.	45 feet.	50 feet.	55 feet.	60 feet.	Basis.
Inches.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Trees.*
10	10.1	9.3	8.8	8.5	8.1	7.7	7.1	6.5	5.8	5.1	4.5	3.8	50
11	11.1	10.1	9.6	9.2	8.7	8.2	7.7	7.0	6.3	5.5	4.8	4.0	50
12	12.1	11.0	10.3	9.8	9.3	8.7	8.2	7.5	6.8	5.9	5.1	4.1	49
13	12.9	11.9	11.1	10.5	9.9	9.3	8.7	8.0	7.2	6.3	5.4	4.3	50
14	13.8	12.7	11.9	11.2	10.5	9.9	9.2	8.5	7.6	6.6	5.6	4.5	50
15	14.8	13.5	12.6	11.9	11.2	10.5	9.7	8.9	7.9	6.9	5.8	4.7	42
16	15.8	14.5	13.5	12.7	11.9	11.2	10.3	9.4	8.4	7.2	6.1	4.9	16
17	16.9	15.5	14.4	13.5	12.6	11.8	10.9	9.8	8.7	7.5	6.3	5.1	12
18	17.9	16.4	15.3	14.3	13.3	12.4	11.3	10.2	9.0	7.7	6.5	5.2	7
19	18.8	17.3	16.0	15.0	14.0	13.0	11.9	10.7	9.4	8.0	6.7	5.4	3
20	19.8	18.1	16.8	15.7	14.6	13.5	12.4	11.1	9.7	8.2	6.8	5.5	2
Total													331

[1] The figures for trees 10 inches and over in diameter in the 60-foot height class, and for all trees in the 70, 80, and 90 foot height classes were originally published in Forest Service Circular 126, and are based on data secured in Gallatin County, Mont. The figures for all trees in the 50-foot height class and for the 7 and 8 inch trees in the 60-foot height class are based on data secured in Deerlodge County, Mont. The figures for 9-inch trees in the 60-foot height class are interpolated.

TABLE 29.—*Stem taper of lodgepole pine as shown by diameter inside bark, Gallatin and Deerlodge Counties, Mont.*—Continued.

TREES 80 FEET IN HEIGHT.

Diameter breast high.	Height from ground.													
	5 feet.	10 feet.	15 feet.	20 feet.	25 feet.	30 feet.	35 feet.	40 feet.	45 feet.	50 feet.	55 feet.	60 feet.	65 feet.	Basis.
Inches.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Trees.*
10	9.7	9.1	8.8	8.6	8.3	7.9	7.5	7.1	6.6	6.0	5.4	4.8	4.3	50
11	10.7	10.0	9.7	9.4	9.0	8.6	8.1	7.6	7.0	6.4	5.7	5.1	4.4	50
12	11.8	10.9	10.5	10.1	9.7	9.2	8.7	8.1	7.5	6.8	6.0	5.3	4.6	50
13	12.7	11.8	11.3	10.8	10.4	9.9	9.4	8.7	8.0	7.2	6.3	5.5	4.8	47
14	13.7	12.7	12.1	11.5	11.0	10.5	9.9	9.2	8.4	7.6	6.7	5.8	4.9	41
15	14.7	13.6	12.9	12.3	11.7	11.1	10.5	9.7	8.9	8.0	7.0	6.0	5.1	38
16	15.8	14.6	13.7	13.0	12.4	11.8	11.1	10.3	9.4	8.4	7.3	6.2	5.2	28
17	16.8	15.4	14.5	13.8	13.1	12.4	11.6	10.7	9.8	8.7	7.6	6.4	5.3	20
18	17.8	16.3	15.3	14.5	13.8	13.0	12.2	11.2	10.2	9.1	7.9	6.7	5.5	10
19	18.7	17.1	16.0	15.1	14.3	13.5	12.6	11.7	10.6	9.4	8.2	6.9	5.6	10
20	19.6	17.9	16.7	15.7	14.8	14.0	13.1	12.1	11.0	9.7	8.4	7.1	5.7	2
Total	......	......	......	......	......	......	......	......	......	......	......	......	......	346

TREES 90 FEET IN HEIGHT.

Diameter breast high.	Height from ground.															
	5 feet.	10 feet.	15 feet.	20 feet.	25 feet.	30 feet.	35 feet.	40 feet.	45 feet.	50 feet.	55 feet.	60 feet.	65 feet.	70 feet.	75 feet.	Basis.
Inches.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Trees.*
12	11.8	10.9	10.6	10.4	10.1	9.8	9.4	8.9	8.4	7.8	7.2	6.5	5.7	4.8	.....	16
13	12.8	11.9	11.5	11.2	10.9	10.5	10.1	9.6	9.1	8.4	7.8	7.1	6.3	5.3	4.3	10
14	13.8	12.9	12.4	12.0	11.7	11.3	10.8	10.3	9.7	9.0	8.3	7.5	6.7	5.8	4.7	3
15	14.8	13.8	13.2	12.8	12.4	12.0	11.5	10.9	10.3	9.5	8.8	8.0	7.1	6.1	4.9	21
16	15.8	14.7	14.1	13.6	13.2	12.7	12.2	11.5	10.8	10.0	9.2	8.3	7.4	6.3	5.2	13
17	16.8	15.6	14.9	14.4	14.0	13.5	12.9	12.2	11.3	10.4	9.6	8.6	7.6	6.4	5.3	8
18	17.7	16.5	15.7	15.2	14.6	14.1	13.5	12.7	11.8	10.8	9.9	8.9	7.8	6.6	5.4	6
19	18.7	17.2	16.4	15.8	15.2	14.6	13.9	13.1	12.2	11.2	10.2	9.1	8.0	6.7	5.5	4
20	19.7	18.1	17.2	16.4	15.8	15.1	14.4	13.5	12.6	11.5	10.4	9.3	8.1	6.8	5.6	7
21	20.6	18.9	17.8	17.0	16.3	15.6	14.8	13.9	12.8	11.7	10.6	9.4	8.2	6.9	5.6	2
22	21.6	19.7	18.5	17.6	16.9	16.1	15.3	14.3	13.2	12.0	10.8	9.6	8.3	7.0	5.7	3
Total	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	93

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 235

Contribution from the Bureau of Entomology, L. O. Howard, Chief,
June 24, 1915.

CONTROL OF DRIED-FRUIT INSECTS IN CALIFORNIA.[1]

By

WILLIAM B. PARKER,[2] *Entomological Assistant, Truck-Crop and Stored-Product Insect Investigations.*

INTRODUCTION.

The State of California is especially adapted to the raising of fruits. It is manifest that only a part of the great crop which is annually produced may be marketed in a fresh condition, since it is impossible to preserve semitropical and other soft fruits for more than a very limited time in the fresh state. The fruit canneries and the dried-fruit industry have accordingly been formed with a view to the utilization of the surplus fruit and have assumed large proportions, the production of dried fruits for the State of California being estimated at 140,000 carloads annually.

The importance of this industry and the fact that numerous inquiries are made concerning the control of the insects which attack dried fruits warrant investigation of the insect enemies of dried fruits in California. This was undertaken in a preliminary way in 1908, but owing to lack of funds was discontinued until 1911, at which time the writer, working under the direction of Dr. F. H. Chittenden, was assigned to this project. The investigation has been continued to the time of publication, and the preliminary notes are herewith submitted.

[1] The observations in this bulletin and the data on life history and habits were obtained in central California, the author having his headquarters at Sacramento, but it is probable that these particulars do not differ materially in other fruit-growing sections of the United States, especially in the eastern and southern fruit regions.

[2] Resigned Aug. 31, 1914.

NOTE.—The writer has been assisted in this investigation by the Roeding Fig Packing Co., the Rosenberg Co., Mr. D. L. Smith, of the Schuckl Co., the California Dried Fruit Exchange, the Robt. Gair Co., and the Petterson Carton Wrapping & Sealing Machine Co., who by their cooperation have greatly facilitated the prosecution of this project. He also wishes to acknowledge the assistance of Mr. R. E. Campbell, of the Bureau of Entomology, who brought to completion some of the experiments detailed in this paper.

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INSECTS CONCERNED IN THE INJURY.

During the progress of this investigation a study of the insect forms most injurious to dried fruits in California has been pursued, with the result that the following species have been collected, the more important being considered later in separate paragraphs.

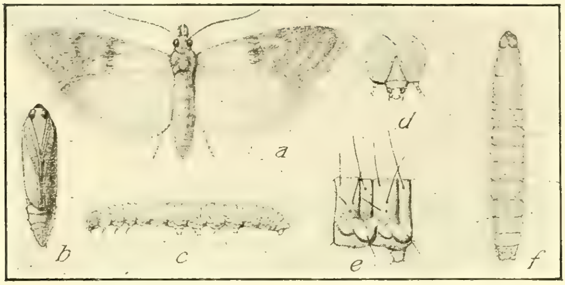

FIG. 1.—The Indian-meal moth (*Plodia interpunctella*): *a*, Moth; *b*, chrysalis; *c*, caterpillar; *d*, head of same; *e*, first abdominal segment of same; *f*, caterpillar, dorsal view. *a*, *b*, *c*, *f*, Somewhat enlarged; *d*, *e*, more enlarged. (From Chittenden.)

The Indian-meal moth (*Plodia interpunctella* Hübn.) (fig. 1) is probably the most common and destructive of these pests, its large size making it particularly conspicuous, while the nature of its attack renders infested fruit most disgusting in appearance. (See Pl. I, figs. 1, 2.) The fig moth (*Ephestia cautella* Walk.) (fig. 2) is next in importance among the moths, while a variety of beetles, including the dried-fruit beetle (*Carpophilus hemipterus* L.), the saw-toothed grain beetle (*Silvanus surinamensis* L.), the foreign grain beetle (*Cathartus advena* Waltl), and a fungus beetle (*Henoticus serratus* Gyll.), are generally injurious. Two sugar mites (*Tyroglyphus siro* Gerv. and *T. longior* Gerv.) are also frequently found. The pomace flies (*Drosophila ampelophila* Loew) attack only the sweet, watery fruits, or those that are fermenting, and can hardly be considered as dried-fruit insects. Ants are occasionally found in dried fruits, but do not breed therein, and can usually be best attacked by destroying their nests outside the packing house.

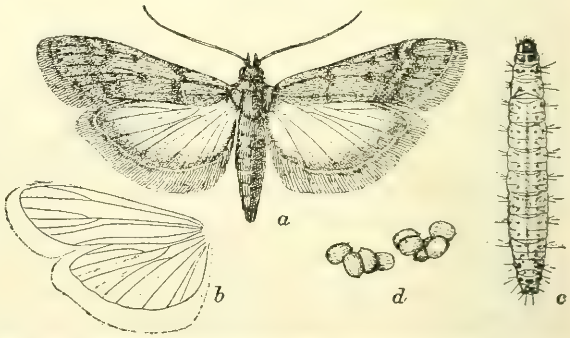

FIG. 2.—The fig moth (*Ephestia cautella*): *a*, Moth; *b*, denuded wing, showing venation; *c*, larva, dorsal view; *d*, two egg masses. *a*, *b*, *c*, Enlarged about four times; *d*, more enlarged. (From Chittenden.)

ECONOMIC IMPORTANCE OF DRIED-FRUIT INSECTS.

The annual financial loss to all who handle dried fruits from the Pacific coast would be very difficult to estimate, since these products are rapidly distributed by the packers over a large territory,

and the injury is first noticed by the retailer or the consumer. Moreover, the retailer is inclined to be somewhat reticent regarding the presence of wormy fruit in his establishment, although an examination frequently shows such to be the case. A few retail grocers stated that the "worms" were especially troublesome during the summer months, and while the majority of those interrogated admitted with reluctance that they ever received wormy fruit, it was, no doubt, present in their stores at the time. Many companies claimed that it would be difficult to secure the exact figures, but admitted that they usually sold a considerable quantity as hog feed during the season. A wholesale grocer stated that his annual loss on dried fruits returned because of insect infestation was about $50, but that the loss in 1912 approximated $150. These are only a few individual instances, and the greatest aggregate loss is through small quantities of infested fruit which are thrown away or sold as hog feed, the retailer preferring the loss of a small quantity of fruit to the trouble of returning it to the wholesaler. It is readily apparent, however, that the annual loss must in the aggregate be considerable.

For the reason that no estimates can be made of the injuries by the Indian-meal moth to fruits in California, it is worth stating that according to figures furnished by Dr. Chittenden in 1910, there was a loss to the peanut industry, through the ravages of this species, amounting to 20 per cent, or, at a conservative estimate, $3,000,000.[1]

PRELIMINARY OBSERVATIONS.

Observations begun in 1911 in central California, with headquarters at Sacramento, with special reference to insects attacking dried figs, were soon extended to all dried-fruit insects. It was found that in most cases insects were present in the field where the fruit is dried, that they were quite numerous around the packing houses, and that they were present in warehouses and stores in sufficient numbers to threaten severe infestation to boxes of dried fruit that might be stored there. There are usually one or more cracks or openings in the boxes (Pl. II, fig. 2) through which an insect or mite can readily crawl. The paper used in lining the boxes does not to any extent prevent their entrance.

These preliminary observations led to the conclusion that the problem could not be successfully combated by attacking it at any one point, but that the methods of drying, storing, processing, packing, and shipping should be investigated.

THE INDIAN-MEAL MOTH.

The life history of the Indian-meal moth (*Plodia interpunctella* Hübn.) will vary with the prevailing temperature, but was deter-

[1] Popenoe, C. H. The Indian-meal Moth and "Weevil-cut" Peanuts. U. S. Dept. Agr., Bur. Ent., Cir. 142, 6 p., 1 fig., Sept. 16, 1912. See p. 1.

mined at the Sacramento laboratory during June, July, and August, 1913, as follows: Egg stage, 6 days; larval stage, 35 days; pupal stage, 12 days; adult, about 14 days. Total, from egg to adult, 53 days, or 1 month and 23 days.

While the subject of this article is practical and based on conditions at Sacramento, Cal., it should be added that in the case of the life history of this species Dr. Chittenden has pointed out [1] that "experiment shows that the insect is capable of passing through all its several stages from egg to adult in five weeks, which furnishes a possibility of six or more generations in a well-heated atmosphere, although in a moderately cool granary or other storehouse four or five broods is probably the normal number per annum."

The sudden appearance of large numbers of larvæ in dried fruit is readily explained by Table I, which shows the number of eggs deposited by six moths which were confined in the laboratory to determine the rate of oviposition.

TABLE I.—*Egg-laying records of the Indian-meal moth.*

No.	Days.								Total.
	1st.	2d.	3d.	4th.	5th.	6th.	7th.	8th.	
1	46	79	36	23	24	16	11		235
2	56	65	27	36	36	21	9		250
3	39	43	34	18	16	6			156
4	16	33	47	64	45	56	12	13	286
5	59	51	55	38	26	5			234
6 [1]									168

[1] The number of eggs in this vial was determined as total and not by days.
Average number of eggs deposited by the six moths, 221.3.

These eggs were deposited mostly during the night.

The life cycle during the summer, as given in a preceding paragraph, is only 53 days. Starting with one fertile female in a packing house on June 15 (provided all of the insects matured), there would be 221 moths by the following August 15, and by August 30 (provided that half of these moths were females) there would be a total of 23,310 larvæ in the dried fruit.

Under natural conditions some of the eggs do not hatch and many of the larvæ fail to mature, but from the foregoing data it is readily understood that a few moths of this species are capable of producing a very severe infestation within a relatively short time, provided that temperature and other conditions are favorable.[2]

[1] Chittenden, F. H. Some Insects Injurious to Stored Grain. U. S. Dept. Agr., Farmers' Bul. 45, 24 p., 18 fig., 1897. See p. 10.

[2] The hymenopterous parasite *Habrobracon hebetor* Say is frequently found attacking the larvæ of the Indian-meal moth, but it has not been observed appreciably to affect the infestation in California.

FIG. 1.—THE INDIAN-MEAL MOTH (PLODIA INTERPUNCTELLA): MOTH ON A DRIED APRICOT. (ORIGINAL.)

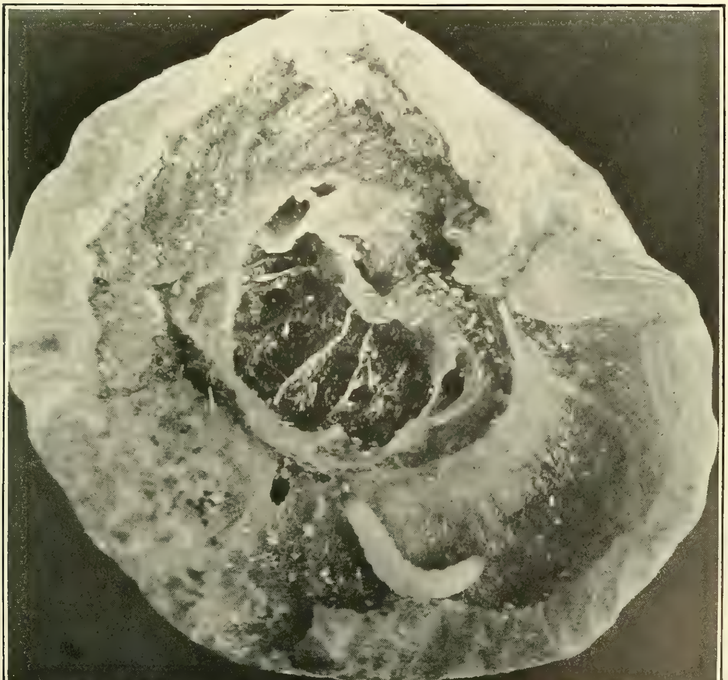

FIG. 2.—THE INDIAN-MEAL MOTH: LARVA ON A DRIED APRICOT. (ORIGINAL.)

DRIED FRUIT INSECTS IN CALIFORNIA.

FIG. 1.—FIGS HANGING ON TREES DURING THE WINTER CONTAINING HIBERNATING ADULTS OF THE DRIED-FRUIT BEETLE (CARPOPHILUS HEMIPTERUS). (ORIGINAL.)

FIG. 2.—THE AVERAGE PACKING BOX, SHOWING CRACKS THROUGH WHICH DRIED FRUIT MAY BECOME INFESTED. (ORIGINAL.)

FIG. 3.—AN INFESTED BOX OF FIGS IN THE ORDINARY PACKING CASE. (ORIGINAL.)

HIBERNATION.

Partly grown larvæ brought into the laboratory October 10, 1913, spent the winter in that stage, pupated in the early spring, and emerged as adults April 16, 1914. Larvæ were observed at various times during the winter in dried fruit and partly spun up in corners and cracks of warehouses. Adults were not observed in warehouses until April 15, when many were found to be emerging. In California this insect appears to hibernate in the larval stage, pupate in the early spring, and emerge as an adult about the middle of April.

THE DRIED-FRUIT BEETLE.

The dried-fruit beetle (*Carpophilus hemipterus* L.) is probably the next in importance as a destructive dried-fruit insect. It is found in large numbers in the figs before they drop from the trees and in bins of figs and other dried fruits. The adults often frequent the packing houses in large numbers, where they swarm over and deposit eggs on the fruit which has been dipped and put out to cool. They breed readily in the moisture of the dried fruits, but apparently can not live in fruit that is moderately dry.

The adult insect hibernates in stored fruit in the packing houses, in figs, and probably in other fruits which are not gathered from the field at the time of harvest. Plate II, figure 1, shows figs which were allowed to remain on the trees during the winter, and which were later found to be highly infested with *Carpophilus hemipterus*.

On September 3, 1911, 5 pounds of dried figs, taken at random from each of seven different dryers in the vicinity of Fresno, Cal., were placed in boxes made insect-proof by plugging all cracks with cotton and wrapping carefully in stout paper. When examined January 13, 1912, the fruit in three of the seven boxes was badly infested. The results of this experiment prove that many figs are infested before they are shipped to the packing house and that the drying sheds are one of the sources of infestation. These conclusions will apply equally well to other fruits. The processing may kill the insects in the fruit at the time of processing but will not protect them from infestation while they are being dried or held in the drying sheds prior to shipping to the packing houses.

It has been found that infestation takes place in the field, in the packing house, in the warehouse, and in the grocery store.

PROCESSING DRIED FRUIT.

Dried fruit from the bins of the packing house is usually quite dry and not particularly attractive or appetizing in appearance. In order to improve its texture so that it will pack well and be attractive to the consumer, it is processed. In Table II will be found the formulas for processing fruit that are in common use in California.

TABLE II.—*Formulas for processing fruit in common use in California.*

Fruit.	Treatment in field.	In packing houses.	Processing.	Packed.
Peach....	Cut in half, sulphured $1\frac{1}{2}$ hours, dried in sun on trays.	Graded and placed in bins not over 4 or 5 feet deep; sweating takes place.	Dipped in cold or lukewarm water, drained, and sulphured.	Moist.
Apricot..	Same as peach......	Same as peach......	Same as peach......	Do.
Pear.....	.....do.............	Same as peach, but handled more carefully.	.....do.............	Do.
Prune....	Picked from ground, dipped in lye solution, rinsed in clear water, dried on trays in sun.	Graded and placed in bins.	Dipped 1 to 3 minutes in clear water at 212° F., drained.	Moist; warm.
Fig......	Picked from ground and dried on trays; or dipped in hot brine, drained, dipped in cold brine-soda solution, drained, and spread on trays, placed in sun until excess moisture is removed, then stacked to complete drying.	.....do.............	Black figs, dipped in boiling brine, drained and packed. White figs, dipped in cold water, drained, and packed; or dipped in boiling brine, drained, and packed. Some are dipped and sulphured.	Do.

FORMULAS.

Brine formula for prunes: Lye, 1 pound to 20 gallons.

Formula for dip for figs before being packed: Salt, 50 pounds; soda, 3 to 4 pounds; water, 150 gallons.

Formula for raisins before drying: One quart olive oil and three-fourths pound powdered caustic soda; water, 1 gallon; cook 30 minutes, add 100 gallons of boiling water with $4\frac{1}{2}$ pounds caustic soda; add more caustic soda if desired.

Amount of sulphur to use and time of exposure based on 1,000 pounds of fruit.

THE EFFECT UPON INSECTS OF PROCESSING FRUIT.

It will be observed in Table II that the processing includes either dipping in boiling brine or sulphuring.

In the case of figs, when removed from the dipping vat they were too hot to be handled. When opened the interior was steaming hot, and it was assumed that no insects could pass through the dip alive. To prove this point, the following experiments were conducted:

On September 3, 1911, 100 pounds of dried figs, thoroughly infested by the dried-fruit beetle and Indian-meal moth, were dipped in the regular dipping solution heated to boiling. Fifty pounds of these figs were immersed in the dip 45 seconds, and 50 pounds were immersed 90 seconds. The figs were protected from insects when cooling, and were later put into boxes and sealed. That this dipping was sufficient to kill all animal life was proved by the total absence

of living insects or of any trace of them when the fruit was examined four months later, January 14, 1912.

That sulphur fumes are more or less effective in killing insects has long been known, but in order to prove their efficiency the following experiments were conducted:

On September 4, 1911, 100 pounds of black figs, which were badly infested by the dried-fruit beetle, were separated and sulphured in the regular manner. Upon being removed from the sulphur box they were immediately placed in cartons and sealed to prevent reinfestation. They were examined January 14, 1912, and no insects or evidence of recent work were observed. The sulphuring killed all insects present in the figs at the time.

An experiment to determine the effect of sulphur fumes upon the eggs of insects was conducted at Sacramento during the summer of 1913. About 25 eggs of the Indian-meal moth, deposited on a dry fig in a vial, were placed in the top of a sulphur box and given the usual treatment. None of these eggs hatched, while the eggs kept as checks hatched in due time.

From the foregoing experiments it is evident that sulphuring the fruit has a tendency to kill any insects infesting it. In case eggs or larvæ are well inside of the fruit, however, it is probable that they would not be injured; and since the use of sulphur is not sanctioned by the authorities, and the use of heat, either wet or dry, is so very effective, the use of a belt heater is recommended.

A BELT HEATER TO DESTROY INSECTS IN DRIED FRUIT.

The belt heater is composed of a chamber in which is run a tier of belts, each running in the opposite direction to the one above it. These are so arranged that the fruit can be fed in at the top and will travel on the top belt until it reaches the roller, when it will fall to the belt below and be carried in the other direction, and so on down, the last belt carrying the fruit out of the chamber. A heater, either electric or steam, is arranged to maintain a temperature of 180° F., and by adjusting the speed of the belts the time that the fruit remains in the heater can be regulated.

An experimental machine consists of six belts, 10 feet long and 5 feet wide, running on 3-inch wooden rollers. The rollers are set on cold-rolled axles, turned by cast-iron sprockets connected by No. 25 chain, which is so arranged that it reverses the direction of alternate rollers. To insure even heating an electric fan is so adjusted that the hot air is blown along the belts, and guides are arranged to direct the air current onto the belts above. Thus, as the fruit is carried along by the belts, the hot air is blown over it. Such a machine arranged to deliver the fruit into a screened packing room (fig. 3) would insure the fruit against contamination before packing.

The fruit should remain in the heater sufficiently long to raise it to 180° F. This temperature will kill all insect life.

PROTECTING DRIED FRUITS FROM INFESTATION.

Although some damage results from the infestation of dried fruit stored in bins in the packing house, the greatest loss occurs after the fruit has been packed.

The fruit which is separated and dipped into hot solutions (212° F.) before being packed is by this process sterilized so far as insects are concerned. It has been found that such fruits as peaches, pears,

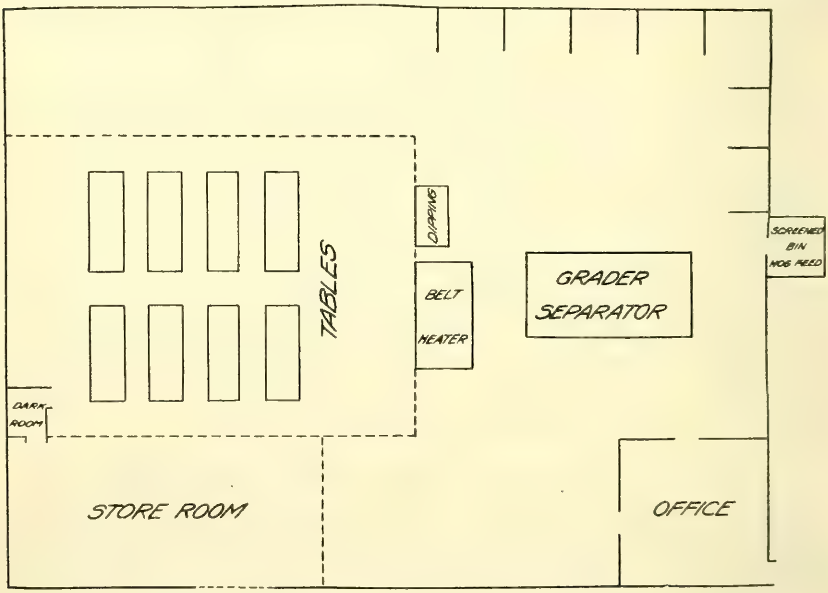

FIG. 3.—Diagram of screened packing room showing belt heater at center. (Original.)

and apricots, which are not dipped in such solutions, can be sterilized by dry heat before they are moistened, preparatory to packing. The major problem is one of preventing infestation after the fruit is sterilized and packed. Successful experiments with the use of a sealed carton (fig. 4) to protect cereals from insect attack[1] led the writer to work out a similar process for dried fruits.

Figs put up in small packages were found convenient for the following preliminary experiments begun at Fresno, Cal., October 1, 1913. Hot figs were taken from the dipping vat, pressed into bricks, wrapped in the regular paper, and placed in cartons. Careful watch was kept for infesting insects, and none was seen near the figs during the packing process.

[1] Parker, William B. A Sealed Paper Carton to Protect Cereals from Insect Attack. U. S. Dept. Agr., Bul. 15, 8 p., 8 fig., Oct. 16, 1913.

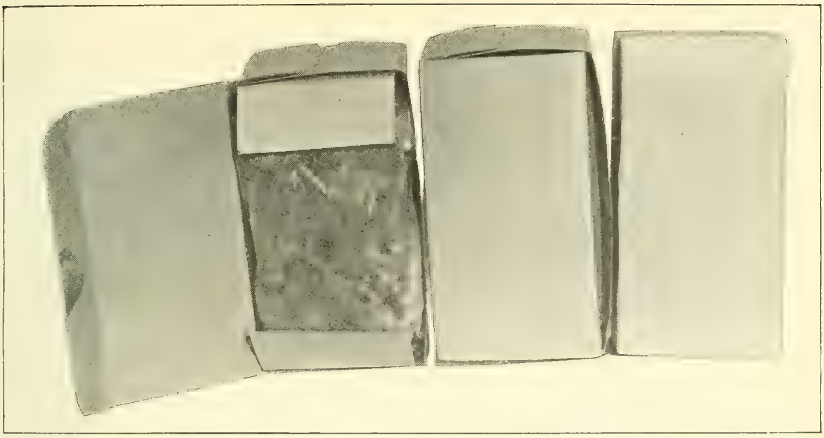

FIG. 1.—PATTERN OF THE INNER SEAL. (ORIGINAL.)

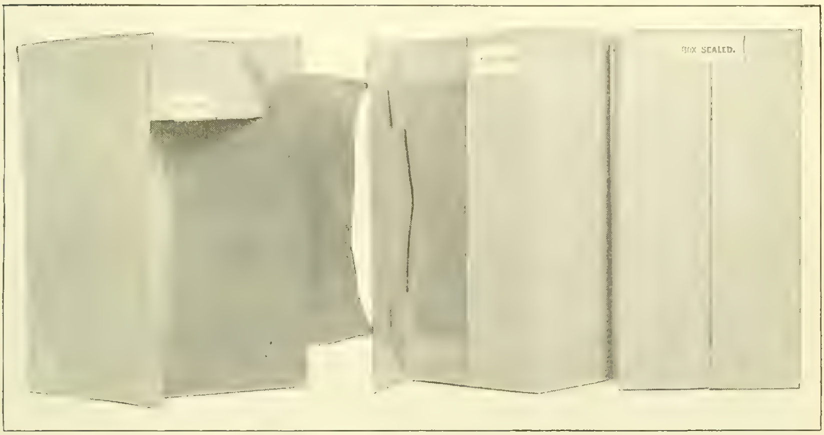

FIG. 2.—METHOD OF USING THE INNER SEAL. (ORIGINAL.)

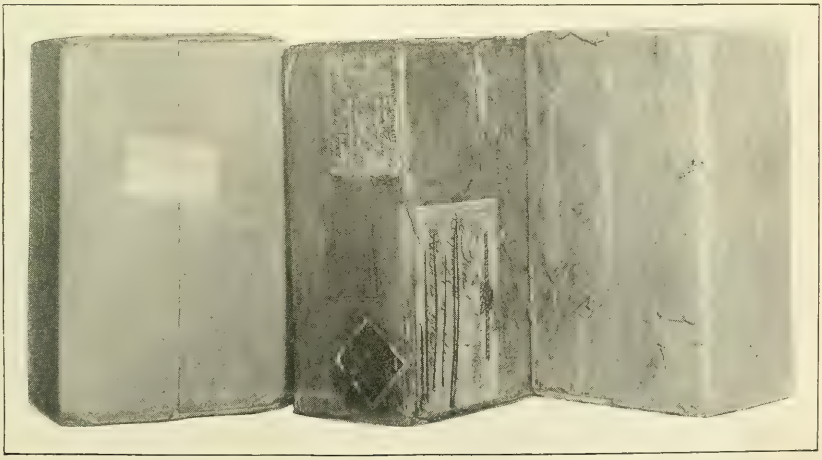

FIG. 3.—HOW THE PACKAGES STOOD THE SHIPPING TEST. (ORIGINAL.)

THE INNER SEAL: A SANITARY INSECT-PROOF PACKAGE.

FIG. 1.—ROUND PACKAGES FOR DRIED FRUIT WHICH CAN BE SEALED. (ORIGINAL.)

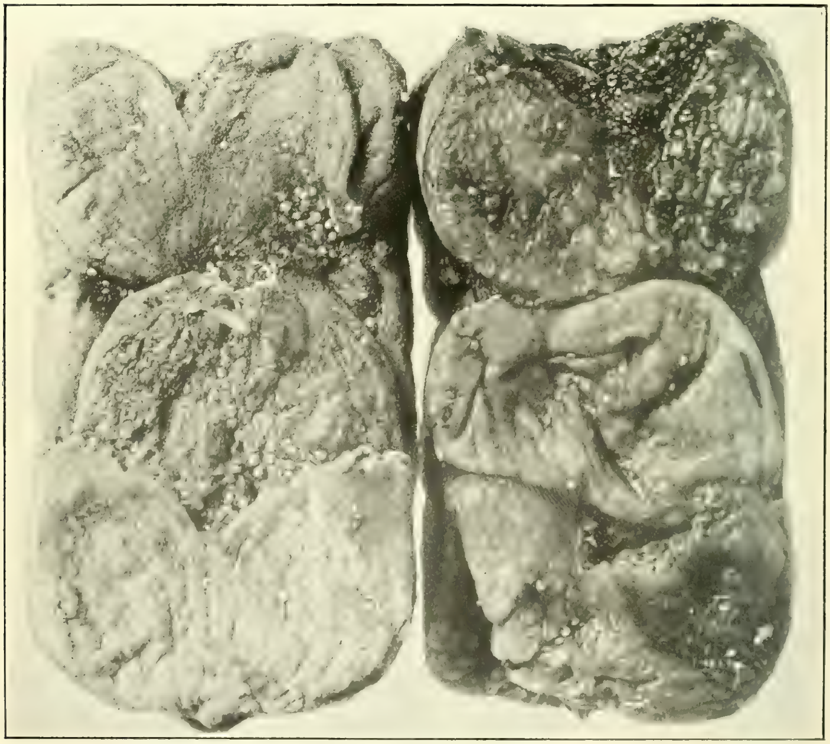

FIG. 2.—BRICKS OF FIGS, SHOWING THE RESULT OF SEALED CARTON EXPERIMENTS.

At left, unsealed brick. Note dried sugaring and infested condition. At right, sealed brick. Note moist condition. (Original.)

Of these cartons 16 were sealed as shown in Plate III, figure 1, and 16 left unsealed. Of the unsealed ones, 8 were so prepared that the wrapping paper was slightly torn. This condition is one frequently found in packages of figs put up by the girls in the packing house.

The 32 cartons prepared as described above were brought to Sacramento and placed in an insect-tight box in which were then placed large numbers of larvæ and adults of *Plodia interpunctella, Carpophilus hemipterus*, and *Gnathocerus* (*Echocerus*) *maxillosus* Fab. The box was then sealed so that the insects could not escape, and they were given every chance to infest the cartons.

At the conclusion of these experiments, April 16, 1914, all but two of the unsealed cartons were found to be infested, while the sealed ones showed no evidence of insects having entered. It was observed that the larvæ of *Plodia interpunctella* had in some places broken through the thin paper used to wrap the bricks of figs before they are placed in the cartons.[1] It had previously been supposed by the packers that this paper if preserved intact would prevent insects from reaching the fruit.

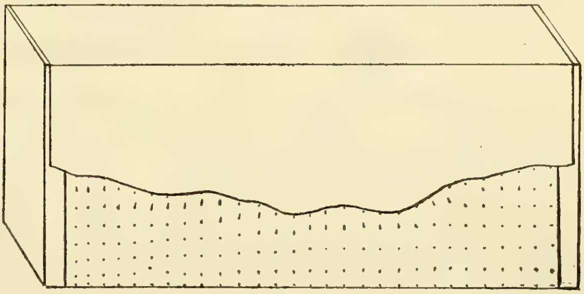

FIG. 4.—Diagram of carton, showing method of applying label to protect inclosed cereal from insect attack. (Author's illustration.)

The foregoing experiments will serve to prove the efficiency of a sealed carton in protecting packed dried fruit from insect attack.

SEALED PACKAGES FOR DRIED FRUIT.

Packages of dried fruit weighing less than 5 pounds are so nearly the size of the cartons used for cereals that, except for the high labor cost of sealing, the method used with the cereal carton could be readily applied to dried fruits. With the 10, 25, and 50 pound packages, however, the cost of such sealing is excessive, and the wooden boxes used can not be thus sealed to advantage, as the seal is easily broken by rough handling. To obviate this difficulty a light paper carton fitting inside the wooden box, and sealed before the top was nailed on, was constructed, but the cost of these cartons and the additional labor required to pack them prohibited the employment

[1] A heavy paraffined paper appears effective in preventing insects from eating through.

of this method. A fiber-board carton was then selected which could be sealed, or in which had been placed an inner seal, to prevent the entrance of insects. Such a package to be successful should stand the same shipping conditions as a wooden box and should not, when sealed, greatly exceed the latter in cost. A carton of the following specifications was tested to determine its shipping qualities:

Certificate of box maker.—This box is made of three-ply or more, fiber board or pulp board, outer ply waterproofed.

Each ply	inch	0.016
Thickness not less than combined board	do	.080
Resistance (Mullen test), combined board	pounds per square inch	200
Dimension limit, length, width, and depth added	inches	65
Gross weight limit	pounds	65

SHIPPING TESTS OF FIBER-BOARD PACKAGES.

Three 25-pound boxes (Pl. III) made according to the foregoing specifications were filled with 25 pounds of dried peaches, sealed, and given the following shipping tests:

Box No. 1 was shipped by express from Sacramento, Cal., to Portland, Me., and back, or about 6,000 miles, during which trip it was handled by at least 18 men. This box arrived in Sacramento in good condition and is shown in Plate III, figure 3.

Box No. 2 was shipped from Sacramento, Cal., to Fargo, N. Dak., as one of the bottom boxes in a car of 25-pound boxes of dried fruit. Except for one place where the sharp edge of a wooden box had worked up the edge, this box arrived at its destination in fine condition, as illustrated in Plate III, figure 3. This rubbing would not occur in a carload of fiber-board boxes.

Box No. 3 was sent to San Francisco by Parcels Post, where it was trucked around the wharves, given a thorough test, and examined by several packers and by the agent of one steamship company. It arrived in Sacramento in good condition, after having stood the test and having been pronounced a good shipping package for dried fruit. (Pl. III, fig. 3.)

The foregoing tests proved that the 25-pound package of dried fruit could be shipped long distances, and its shipping qualities compared very well with the wooden box.

These fiber-board boxes (Pl. III) weigh much less than the wooden box, and the saving on the freight would be considerable. In the case of the 25-pound box the saving per car on the basis of $1.10 per 100 (freight rate) is about $23. It was estimated that the adoption of this style of package would save one company approximately $40,000 annually.

THE SEAL.

The fiber-board package was found to be tight, except at the corners and where the flaps meet in the middle of the sides. An attempt was made to seal these places with gummed tape, but the labor required to do this increased the cost of packing to such an extent as to make the method unfeasible.

An inner seal was then so constructed that when the carton was regularly sealed there would be no cracks or openings at the corners. (See Pl. III, fig. 1.)

The inner seal appears practical from the packer's point of view, but the carton manufacturer claims that it would be difficult to make it cheaply enough without special machinery, although this would probably be made were there a demand for such cartons.

ADVANTAGES OF THE SEALED CARTON FOR DRIED FRUIT.

As long as dried fruit can be processed so that mold is no more prevalent in sealed packages than in unsealed ones the disadvantages of this type of package, with the possible exception of the extra cost, are negligible. The advantages, on the other hand, are several.

The main object of the sealed carton is the exclusion of infesting insects. This is accomplished very successfully and so solves a large portion of the present problem.

It also prevents the evaporation of moisture from the fruit, and thus for a long time preserves the fruit in the same moist condition in which it was packed. Plate IV, figure 2, shows two bricks of figs packed October 1, 1913, and opened April 16, 1914. The brick on the left was put up in an ordinary carton, and, as will be observed, it was dried, sugared, and became infested, while the one on the right, which was put into an ordinary carton, but sealed, is in practically the same condition as when packed. These two bricks were kept under the same conditions; in fact, were in the same box. From the foregoing data it is evident that fruit properly packed in sealed cartons will be protected from infestation and will remain in a moist condition much longer than when packed in an ordinary carton or box.

OTHER SEALED PACKAGES.

In an attempt to find a small and attractive package for their fruit one packing company in California evolved a round carton with a cover that fitted over the end like the cover of a baking powder can, as shown in Plate IV, figure 1. A printed label pasted around the edge of the carton formed in experiment a very effective seal. This carton appears to be satisfactory for small packages, but the shape is such that more room is required for shipment than is the case with the square package, and it is not as practical for the larger sizes.

When objections to the inner seal were presented the writer immediately investigated other possible methods. Among several which were suggested, the use of a waxed sealing paper wrapped around bricks of fruit and sealed with a hot iron seemed very promising.[1] It was found that bricks of apricots, prunes, and pears up to 10 pounds in weight could be successfully made and wrapped in the waxed paper, and that by placing a piece of sheet iron on top of the brick of fruit before folding the paper over, a smooth surface could be obtained for the application of the sealing iron. After the top is sealed the sheet iron should be quickly removed. The hot iron may then be applied to the ends of the paper, making them tight, and afterwards the ends may be folded up and the brick placed in a large carton. Plate V, figures 1 and 2, shows the effect obtained by using such a paper seal, which, when properly sealed, renders the package insect proof. The cost of packing dried fruit in such a package has not been determined, but the writer believes that it will be found economical in many packing houses.

This method combines the advantages of an insect-proof package, a 5 or 10 pound unit, and a 25 or 50 pound fiber-board carton, which is lighter and probably cheaper than the wooden box.

While in the field the writer observed a package formed of an ordinary raisin carton which was sealed in a waxed sealing paper. The sealing was done by machinery which, except for the initial expense of the machine, would make the process very rapid and economical. Such a package might prove very efficient for dried fruits put up in from 1 to 5 or even 10 pound packages.

Several packers have reported the presence of mold in the ordinary wooden boxes of dried figs. Plate VI, figure 1, shows such a condition. This was observed to occur more frequently in the sealed round boxes previously mentioned, and it appears that if the sealed carton is to be used for dried fruit the problem is a very important one.

From examinations of moldy fruit and from investigations of the condition of the fruit when packed, the writer concludes that conditions favorable to the growth of mold occur only when the fruit is too wet when packed, either through excessive processing or improper drainage. One packer stated that when the fruit was taken directly from the hot dip and packed in sealed boxes a large percentage of the cartons became moldy. On the other hand, if the fruit was allowed to drain thoroughly and stand in lug boxes or in a heap for several hours before being packed, the moisture became equalized and mold rarely developed. (Pl. VI, fig. 2.) To establish these statements and observations finally the following experiments were conducted:

On July 28, 1914, four lots of figs were processed by dipping in boiling water for one minute. Lot No. 1 was dried in the sun until

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[1] Suggested by Mr. J. H. Green, of San Francisco.

FIG. 1.—A CARTON WRAPPED AND SEALED BY THE MACHINE. (ORIGINAL.)

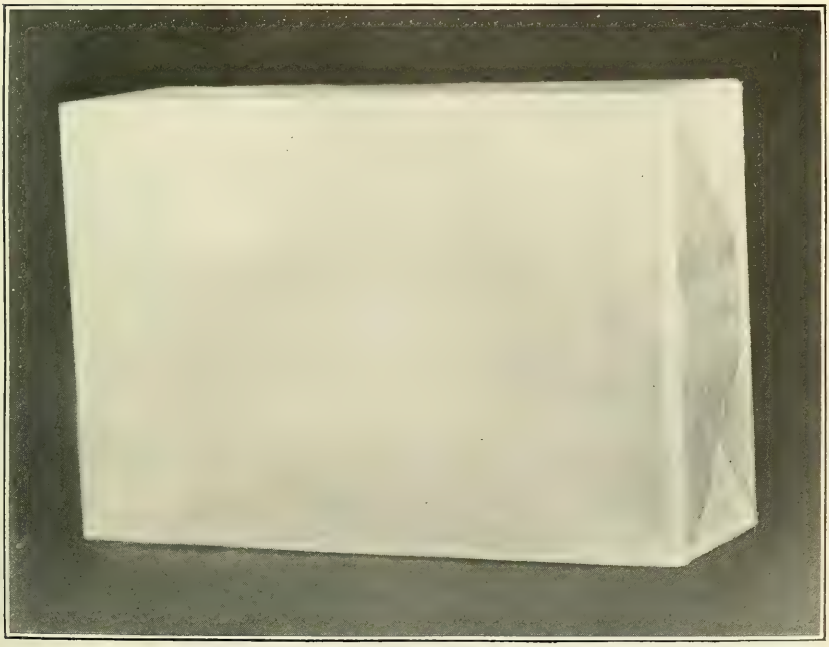


FIG. 2.—CLEAN AND WHOLESOME; MOISTURE AND INSECT PROOF. PARAFFIN-WAXED PAPER SEAL APPLIED TO A CARTON OF RAISINS. (ORIGINAL.)

INSECT-PROOF PRODUCTS OF THE WRAPPING AND SEALING MACHINE.

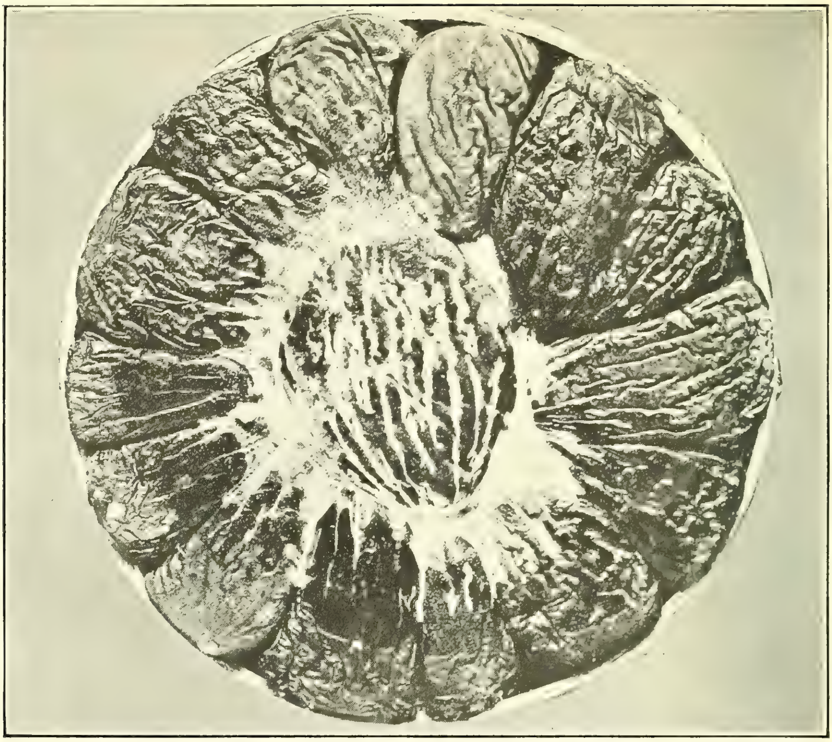


FIG. 1.—MOLDY CONDITION OF FIGS IN ROUND SEALED CARTON. FIGS PACKED TOO WET. (ORIGINAL.)

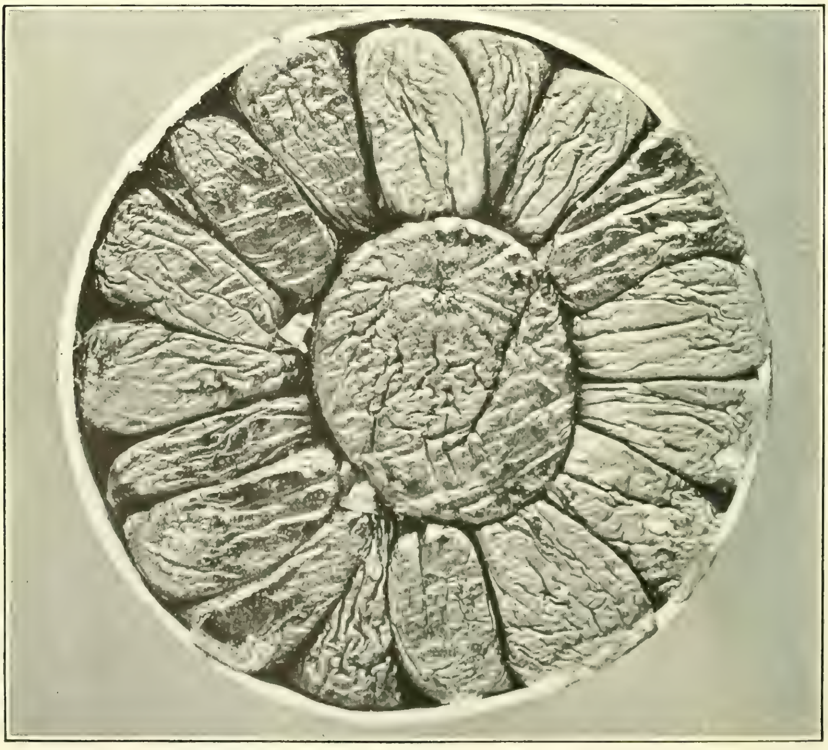
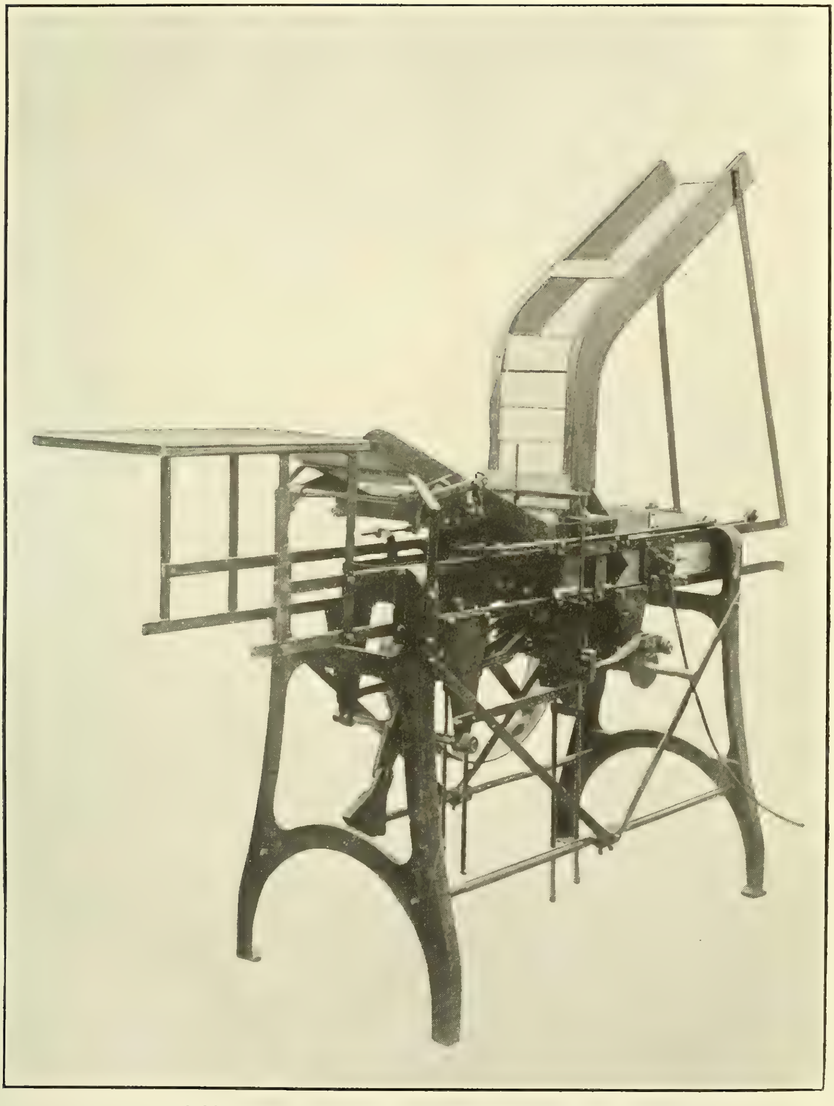


FIG. 2.—PERFECT CONDITION OF FIGS PACKED IN ROUND SEALED CARTONS. EXCESS MOISTURE REMOVED BEFORE PACKING. (ORIGINAL.)



A VALUABLE ADJUNCT TO INSECT-PROOF PACKING.

A carton wrapping and sealing machine, with a capacity of 10,000 per day of 8 hours, at a total cost of less than $1 per thousand. (Original.)

all the surface moisture was gone. Lot No. 2 was dried in the sun a few minutes. Lot No. 3 was allowed to drain and cool thoroughly in the shade. Lot No. 4 was allowed to drain a few minutes and was packed while still hot and damp. All were packed in Mason jars, infected with spores from growing fungus, and sealed up.

On examination one month later no fungous growth was found to have developed on Nos. 1, 2, and 3, but No. 4, the lot which was packed wet and hot, had a very good growth of the fungus.

The experiment was repeated on September 1, dipping the figs in the hot water three minutes instead of one. On examination two weeks later it was found that in lot No. 1 no growth of fungus had developed. In lots 2 and 3 slight growths were present, and in lot 4 a heavy growth. The same figs were used in both experiments, and by the time they had been put through the boiling water the second time their surfaces were softer and stickier than they should be, and hence were good media for fungous growth.

These experiments confirm the earlier observations, namely, that figs thoroughly drained or dried and cooled before packing are less likely to develop fungous growth than those packed while still damp and warm.

A CARTON WRAPPING AND SEALING MACHINE.

Several machines are now being manufactured which do away with the slow and expensive method of wrapping and sealing cartons by hand. Such a machine is shown in Plate VII. The cartons are fed into the hopper at the top and the waxed paper is fed automatically or by hand. The machine wraps the waxed paper neatly and tightly around the carton and seals it air-tight by means of electrically heated plates. One operator is required when equipped with the automatic paper feed, and two without. This particular machine was made to wrap cartons 8 by 3 by 3 inches. It will wrap and seal a minimum of 25 to 30 per minute, or about 10,000 per day of eight hours. The cost based on this output, including the waxed paper, wrapping, sealing, power to operate, and wages of the operator, will be less than $1 per 1,000. The maximum output will be from 15,000 to 20,000 cartons per day, with a cost at this rate of from $0.80 to $0.90 per 1,000.

At present, by the hand-wrapping method, one girl will average 1,000 cartons per day. Thus the machine will easily do the work of a dozen or more girls.

The cost of hand-wrapping the package referred to is given as $1.75 per 1,000. Using the minimum output of the machine for comparison, the saving in one day's run would be over $7, at which rate the machine would pay for itself in less than four months, since it may be purchased capable of handling any size of carton desired by the purchaser at a retail price of about $600.

A machine of this nature would be available and practical not only for wrapping and sealing cracker and cereal cartons, but also for raisins, currants, figs, prunes, and all small packages of other dried fruits.

PREPARATION OF A STERILE PACKAGE OF DRIED FRUIT.

A description has been furnished of a method of preparing packages of cereals so that they will not become infested. This process is being successfully carried out by several large mills, the only real difficulty arising from the cost of sealing the carton. This objection is being gradually overcome.

The process consists in running the cereal through a sterilizer and then through a clean chute directly into an insect-free packing room, where it is packed in sterilized cartons and sealed. The writer believes that such a process can be applied to dried fruit, and the following suggestions are made to that effect:

In order to sterilize the fruit so far as insects are concerned it is necessary to heat it to 180° F. With the fruits which are regularly dipped in hot solutions this heating is readily accomplished, but in the case of those which are dipped in cold solutions before being packed the use of the belt heater described on pages 7–8 is suggested.

After sterilization by one of the foregoing processes the fruit must be protected from reinfestation, and the use of the screened packing room, a plan for which is shown on page 8, figure 3, and described below, will serve this purpose nicely.

The fruit should be run directly from the sterilizer or dipping vat into the packing room, where it is packed and sealed. It may then be removed to a warehouse, and if properly sealed it will not become infested by insects.

THE SCREENED PACKING ROOM.

A simple packing room (fig. 3) can be cheaply constructed by covering a light framework with lath, cloth, and paper. The windows, the floor, and all corners and joints should be made tight, and ventilation accomplished by blowing air through an opening covered with cheesecloth or No. 20 screen wire. Such a packing room can be constructed to admit plenty of light and air and still be free from insects. Whenever necessary the openings may be closed and the room thoroughly fumigated.

NOTE.—The writer has observed as many as 10 eggs of insects on the inside of a carton in a cereal mill. It is advisable, therefore, to sterilize all cartons before filling them. This may be readily done by placing a truck load in a heating chamber over night or during the day.

SUMMARY AND CONCLUSIONS.

The foregoing observations and experiments have brought out the following points:

A considerable financial loss due to the infestation of dried fruit by insects is experienced by packers, wholesale men, and retail dealers.

There are several species of insects which attack dried fruits on the Pacific coast, but of these the most common and destructive are the Indian-meal moth and the dried-fruit beetle.

Infestation takes place in the packing house, in the warehouse, and in the grocery store. The insects find their way to the fruit through small cracks in the boxes and between the folds of the paper.

All insect life is destroyed in fruits that are put through the boiling dip, and the processing of other fruits can be accomplished by the addition of the belt heater to sterilize all fruit so treated.

The use of an insect-free packing room and sterilized cartons or containers which are sealed before being placed in the warehouses or cars will protect the fruit from infestation unless the package is broken.

There are several cartons and methods of sealing that can be applied to dried fruit, but their cost will determine their practicability.

The secret of preparing an insect-free package of dried fruit is to sterilize it at a temperature of 180° F. and protect it from future infestation by the use of the insect-free packing room and sealing in sterile cartons or packages.

The sealed carton not only protects the fruit from infestation, but it prevents it from drying out and preserves it for long periods in the moist and attractive condition in which it was packed.

Moist fruit can be successfully packed in sealed cartons, provided attention is paid to the moisture content. The fruit must be carefully drained and must not be packed too hot.

Machines have been invented which will successfully wrap and seal small packages of dried fruit at a moderate cost per thousand.

It is probable that the time is coming when it will be as necessary to put up dried fruit in sealed packages as it is to pack cereals in that form to-day.

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No. 236

Contribution from the Office of Markets and Rural Organization,
Charles J. Brand, Chief.

May 1, 1915.

A SYSTEM OF ACCOUNTS FOR FARMERS' COOPERATIVE ELEVATORS.

By JOHN R. HUMPHREY, *Assistant in Cooperative Grain Elevator Accounting*, and
W. H. KERR, *Investigator in Market Business Practice*.

CONTENTS.

INTRODUCTION.

The rapid growth of the business of cooperative grain elevators has emphasized the importance of adequate accounting systems. It has been realized that the adoption of a uniform system sufficiently comprehensive to accommodate itself to the conditions prevailing in the grain-producing States would be a step in advance. This bulletin describes a grain elevator accounting system which has been devised by the Office of Markets and Rural Organization and which is now being used by representative elevators in seven of the leading grain-producing States.

In drawing up the various forms comprising this system reference has been made to many other systems now in operation. A first-hand study of conditions existing in the elevator business has likewise had a bearing on the final form of this system.

NOTE.—This bulletin is intended for all farmers' cooperative and other elevators throughout the United States. It contains copies of forms and a description of their uses for a system of accounts which is being recommended by the Office of Markets and Rural Organization, United States Department of Agriculture, as a uniform system for farmers' cooperative elevators.

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TYPES OF ELEVATOR ACCOUNTING SYSTEMS.

Investigations in respect to accounting in cooperative grain elevators have established the fact that no system has been generally accepted as standard. The idea of double-entry bookkeeping, while existing in a thorough sense in only a limited number of elevators, is followed more or less vaguely in all, and for that reason there is found every variation in type from patented systems to mere handbook entries kept in memorandum form for the benefit of the manager.

All the systems of bookkeeping now existing in elevators may be classified under three general headings: Complete double-entry systems kept in the elevator; incomplete systems, consisting of reports and memoranda kept in the elevator; and complete systems of reports made up at the elevator and sent to some outside agency where the records of the company are kept.

Of the three, the first should prove the most satisfactory for the reason that, although the third system may furnish definite information, the details of that information are not, as a rule, within easy reach of the men who are most interested in them.

The benefits to be derived from a complete double-entry system of bookkeeping, so constructed that it can be adopted by all elevators, are: First, the possibility of distributing and interchanging valuable statistics among elevators; second, the training of managers and bookkeepers, so that they will obtain a cumulative knowledge of elevator accounting, thus making it easier to procure competent help in these lines; third, the individual benefit derived by each elevator from knowing its financial and business condition with accuracy at short notice; and, fourth, the benefit to future buying in being able to ascertain the average net cost per bushel of operating an elevator.

OFFICE EQUIPMENT.

No system of accounts can be efficient unless it is properly handled. Office equipment is one of the important factors relating to the success of office work. An elevator office should be equipped with fireproof safes or a vault in which all valuable records of the company should be kept. It should have proper filing devices and sufficient furniture, including a standard bookkeeper's desk, to make thorough work possible. When the business of an elevator is large enough to justify the employment of a bookkeeper, such trained help should be secured, as, in most instances, the elevator manager is either without the knowledge or the time to perform the duties of a bookkeeper.

TAKING AN INVENTORY.

At the end of the business year or at the "cut off," an inventory should be taken. This should be an actual physical inventory, taken

either by measurement of the grain in the bins or by running it out of the bins and through a hopper or automatic scale, thus getting actual weights. The practice of taking estimated inventories by reference to the reports accumulated during the year's business is dangerous and, in most cases, absolutely inaccurate. The average platform scale has a weighing error of from 3 to 15 pounds per 60-bushel load. This weighing error accumulating during a whole year sometimes amounts to a shortage or "overage" of hundreds of bushels. By taking inventories from grain reports, the elevator may, after five or six years, find itself with a book grain stock out of all proportion to the actual grain on hand at the time of inventory. By taking an actual inventory, the shrinkage or "overage" of each kind of grain is accounted for within the year to which it applies, and, if abnormal, can be checked up easily if an actual inventory has been taken the season before.

AUDITING THE BOOKS.

One of the features in elevator bookkeeping upon which great stress should be laid and to which an important position should be assigned is the auditing of the books as soon as the inventory has been taken. The custom prevailing among farmers' elevators of having internal audit committees furnished from the board of directors or the stockholders is commendable only to the extent of its usefulness in keeping the directorate in close touch with the business of the elevator. The positive value of such an audit, in so far as it is able to detect errors of principle or even clerical errors, is negligible, since, as a rule, the men making the audit are not especially trained for such work and use very little time to complete their reports. It should be apparent, then, that it is good business practice to secure the services of a certified public accountant who has had sufficient practice in elevator accounting to be able to give vital information and advice to the manager and directors of the elevator. Internal audit committees may work in conjunction with such an auditor, thus shortening the period of his labors as well as benefiting themselves by contact with him. The item of cost in connection with the hiring of public accountants has been the deterrent factor which, to a great extent, has kept the farmers' elevators in the past from availing themselves of such services. By banding together, several cooperative elevator companies might give an accountant steady employment throughout the year and secure his services at a greatly reduced rate.[1]

[1] For further discussion of auditing, see U. S. Department of Agriculture Bulletin No. 178—Cooperative Organization Business Methods.

HEDGING.

As a protection or insurance against loss from price fluctuations between the time of purchase and the time the grain is sold, an elevator may hedge its holdings. When grain is taken into the elevator it can be immediately protected by its sale for future delivery. When the grain is sold the hedge is taken up; that is, a purchase for future delivery is made. If the price of cash wheat has fallen in the meantime, the loss is counterbalanced by the profit on the hedge, as the future price will have decreased with the cash price. In this manner an elevator protects itself against loss by the drop in the price and waives the profit which might be made in case the price increased. Doing business in this way eliminates all chance of large losses or gains in the fluctuations in prices which take place from the time the farmer is paid for his deliveries until sales are made.

Dealing in futures should be allowed only where actual grain is hedged. Only lots of 5,000 bushels of wheat can be bought or sold for future delivery. Since an elevator often desires to protect smaller amounts, commission firms generally will accept orders for purchases or sales of futures in smaller quantities, say lots of 1,000 or 2,000 bushels. The commission firm then assembles its various orders and secures trades in lots of 5,000 bushels.

INSURANCE OF ELEVATORS.

The practice of insuring against fire is a well-established principle in respect to all property, but carelessness in keeping insurance which is sufficient to cover total loss has proven disastrous in many instances. Owing to the marked fluctuation in the amount of grain on hand during the shipping season, grain elevators particularly are likely to be underinsured. For convenience, it is advisable to insure buildings and contents under separate policies. The policy covering buildings seldom varies in amount during the year, but that covering grain may be subject to change. Some managers in small towns, where no insurance agent is stationed, have protected their grain stock by insuring for maximum capacity. Others make arrangements with the agent allowing for changes on notice, and thus effect a saving in premiums paid.

DESCRIPTION OF THE OFFICE OF MARKETS AND RURAL ORGANIZATION GRAIN ELEVATOR ACCOUNTING SYSTEM.

As this bulletin is intended to be sufficiently complete to enable an elevator company to install the system as devised by the Office of Markets and Rural Organization, a detailed description of the forms comprising it is essential.

The complete system includes 15 forms, as follows:

Form No. 1—Cash, journal, purchase and sales record.
Form No. 2—Record of grain receipts.
Form No. 3—Record of grain purchases
Form No. 4—Record of grain shipments and sales.
Form No. 5—Record of hedges.
Form No. 6—Record of sales to arrive.
Form No. 7—Patronage ledger.
Form No. 8—Grain and merchandise report.
Form No. 9—Manager's report.
Form No. 10—Grain check.
Form No. 11—Scale ticket.
Form No. 12—Storage ticket.
Form No. 13—Sales ticket.
Form No. 14—Cash receipt.
Form No. 15—Cost analysis.

For convenience of discussion, the description of the foregoing forms will be taken up in respect to the order of their use.

SCALE TICKET.

Form No. 11 (see p. 26) represents the scale ticket adopted under this system, but it is not essential that this exact form should be used, as any scale ticket which records gross, tare, and net, and gross dockage, and net of the load, together with designations as to the owner and kind of grain, will be satisfactory.

STORAGE TICKET.

In order that all grain may be accounted for properly upon receipt by the elevator, the adoption of the storage ticket as a means of recording bushels and pounds received is strongly recommended. Form No. 12 (see p. 27) represents such a ticket. Upon this ticket are recorded the gross dockage and net of all the loads which have been hauled in any one day by a single owner, as previously recorded on scale tickets. Storage tickets should be made up at the close of business each day. Both scale and storage tickets should be numbered consecutively and printed in duplicate.

For convenience in referring to the data entered on storage tickets it is advisable to file the tickets alphabetically under two headings, denoting "stored grain" and "purchased grain." By this system of filing, each patron's sales are kept together and settlement may be effected easily in the case of unsold grain through reference to this file. A small card file containing a card for each patron may be found of assistance in listing numbers of storage tickets and for furnishing other information for checking up the storage-ticket files.

RECORD OF GRAIN RECEIPTS.

After having registered all the receipts of grain on storage tickets under the names of their respective owners, entry should be made

on the record of grain receipts (Form No. 2, facing p. 20), where the date, storage-ticket number, the kind, grade, and bushels of grain are noted.

GRAIN CHECK.

In buying the grain a special grain check should be used (Form No. 10; see p. 25), upon which are recorded, in addition to the information usually contained in a check, the number of bushels and kind of grain, together with the purchase price, minus any deductions for storage or accounts receivable, and the resultant amount of the check. Regular checks should be used for all expense and general items.

RECORD OF GRAIN PURCHASES.

These checks, being numbered consecutively, are entered according to number upon the record of grain purchases (Form No. 3, facing p. 20), where the net bushels, storage, and cost of grain are recorded in detail.

RECORD OF GRAIN SHIPMENTS AND SALES.

Shipments from the elevator are recorded upon the record of grain shipments and sales. (Form No. 4, facing p. 20.) Here the date of shipment, the party to whom the grain is consigned, the car number, and shipper's weight are recorded. As soon as the shipment has been sold and the returns have been received the date of sale, price received, destination, grade, and proceeds received for the grain are entered.

RECORD OF HEDGES.

A record of hedges (Form No. 5; see p. 21) is a form designed to record the transactions in futures bought and sold. The columns designated "Purchase and sales accounts" are used to record profits or losses on hedges, the "Remarks" column being used to designate the broker through whom the profit or loss is incurred.

RECORD OF SALES TO ARRIVE.

A considerable number of elevators selling grain "to arrive" have no form upon which the transactions can be recorded. Form No. 6 (see p. 21) represents a record of sales to arrive. A brief study of this form will be sufficient to demonstrate its usefulness. It has no part in the accounting system except as a memorandum of shipments made against contracts, but this is important in itself.

MANAGER'S REPORT.

Some elevators which are not doing sufficient business to warrant the hiring of a bookkeeper and in which the elevator manager is unable to keep the books have found it convenient to secure the services of a bookkeeper employed either in a bank or some store of the town in which they are located. For such elevators a manager's report

(Form No. 9; see p. 24) has been provided. Upon this report the manager records all the transactions in receipts and purchases of grain and incloses duplicates of sales tickets covering sales of merchandise and of receipts for cash. From this form the bookkeeper, although not employed in the elevator, is able to keep the system of records in a satisfactory manner. The records of disbursements covering incidental items in most cases are controlled by the secretary or treasurer, and the bookkeeper should ook to him for records of this type.

PATRONAGE LEDGER.

In a few States cooperative laws have been enacted enabling cooperative organizations to distribute dividends upon a patronage basis, and for elevators operating under this law a patronage ledger has been devised (Form No. 7; see p. 22), upon which are recorded the individual purchases and sales of merchandise under the name of each customer.

GRAIN AND MERCHANDISE REPORT.

At the end of the year, just before balancing the books, an inventory of all merchandise on hand should be taken. Form No. 8, grain and merchandise report (see p. 23), has been provided with suitable headings so that the amounts of grain and merchandise on hand can be recorded. This form serves a valuable purpose in giving the value of net and stored grain on hand at date, from which comparisons can be made showing the amount of stored grain sold.

CASH, JOURNAL, PURCHASE, AND SALES RECORD.

Previously it has been usual to provide a cashbook, journal, and daybook under separate forms in elevator systems. In the system herein described these books, together with a record of purchases, have been incorporated into one form (Form No. 1, facing p. 20), called the cash, journal, purchase, and sales record. As all the forms comprising this system, with the exception of reports and the patronage ledger, are in loose-leaf form, they may be contained in one binder (and the consolidation of four books under one form is a further condensation of the work). In the cash, journal, purchase, and sales record are recorded all regular cashbook entries, such as receipts of money and disbursements through checks, together with all journal entries and records of local sales of merchandise. Purchases of material such as flour, coal, etc., are recorded under "Purchases," giving pounds and amount.

SALES TICKET.

All the local sales of merchandise are originally entered upon the sales ticket (Form No. 13; see p. 28), and these sales tickets are made up in pads of 50 originals and duplicates, numbered consecutively.

CASH RECEIPT.

All receipts of money other than checks are recorded upon a cash receipt (Form No. 14; see p. 29). It is quite essential that such a receipt be used, as the practice of receiving scrip or coin without making a record of the transaction at the time of receipt often leads to discrepancies which are difficult to account for later.

COST ANALYSIS.

A feature of this system and one upon which considerable emphasis should be laid is a cost analysis (Form No. 15; see p. 30), by which the relative amounts of grain handled and the actual and relative cost per bushel are determined. Upon this form a determination of the percentage of cost in handling merchandise is also worked out. The value of knowing the ratio of costs in the operation of a business is a well-established essential in many commercial enterprises, and it is no less important to the successful operation of grain elevators.

In conjunction with this system any double-entry, loose-leaf ledger accommodating general accounts and accounts receivable may be used. To be assured of the correctness of entries, it is advisable that a trial balance be taken from the ledger at the end of each month.[1]

INSTRUCTIONS FOR OPERATING THE SYSTEM.

RECORD OF GRAIN RECEIPTS.

The record of grain receipts (Form No. 2, facing p. 20) is a consecutive record of the receipts of grain as shown on the storage tickets. Having entered the storage tickets consecutively for the period of a month, distributing the grain under the proper columns and recording it under gross dockage and net, in bushels and pounds, we may at the end of the month total this form to arrive at the total grain receipts for the period. The totals of the record of grain receipts are then carried to the grain report opposite the words "receipts this period." As the business progresses from month to month, each month's total should be kept separate; and, at the same time, a total should be drawn down, including the current month and the previous months of the current year. This total is also carried to the grain report opposite the words "gross receipts." Under this system all grain is considered as theoretically stored regardless of whether it is purchased at the time of delivery or actually held in storage. This method is followed because it insures the proper accounting for every bushel of grain which comes into the elevator.

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[1] See U. S. Department of Agriculture Bulletin No. 178, "Cooperative Organization Business Methods," for further explanation of the value of trial balances.

RECORD OF GRAIN PURCHASES.

The record of grain purchases (Form No. 3, facing p. 20) is a record of the net bushels and value of the grain purchased, together with storage which has accrued on the grain up to the time of purchase. Both the bushels and value of all grain recorded on this form should be totaled on dates to agree with the totals of the record of grain receipts. Like the record of grain receipts, the record of grain purchases should be totaled monthly. The totals showing the amount purchased for the year are carried to the grain report opposite "gross purchased." The total amount of all checks issued for grain in any month should be carried to the cash, journal, purchase, and sales record and there entered in the "bank withdrawal" column in one amount. The total cost of the various grains is then carried to the debit of the "grain accounts" in the "general ledger" column of the same form, this constituting a consolidated cash entry for all the transactions in grain purchases for the month. Where storage charges are represented, they should be credited to the "storage account" in the "general ledger" column, and in such cases the cost of grain should equal the amount of the check plus the storage charges, because the storage charges are deducted from the grain cost in order to arrive at the amount of the check.

RECORD OF GRAIN SHIPMENTS AND SALES.

The record of grain shipments and sales (Form No. 4, facing p. 20) carries a record of all cars shipped and the net returns from each shipment. The proceeds from each variety of grain should be totaled and posted at the end of the month to the credit of "grain accounts" in the general ledger. The items in the "net proceeds" column should be posted to the debit of the grain commission accounts represented in the "shipped to" column. The monthly totals of bushels from this form should be carried to the grain report opposite "shipments and sales this period." In the operation of this form it will be found that some of the shipments for any month will be still standing out as grain in transit at the end of the month. In beginning a new month, the 1st of April, for instance, it would be necessary to make an entry for the month of March as follows: "Total March returns on February shipments"; opposite this would be set down in total the net returns of all February shipments which had been received during March. In order to avoid confusion, however, reference should be made to February entries for posting to the individual "commission accounts." By this method the total returns on all grain will have been posted to the proper "commission accounts" by individual postings. Although we post only totals to the credit of the "grain accounts," the total receipts on each kind of grain shipped during the previous month

and returned during the current month can be added in with the March shipments and returns in order to arrive at the total amount of returns for the month of March. This same method will apply if a car shipped in February should not bring returns until April, as the February entry would show that the car was still standing out through the month of March.

RECORD OF HEDGES.

A record of hedges (Form No. 5; see p. 21) is essential to the proper hedging of grain, and this account should be kept up to date. On this form columns have been provided giving all the necessary information for keeping the accounting record of grain hedges. Profit or loss on hedges should be posted to the general ledger to the debit or credit of the "commission account" represented and to the debit or credit of "profit and loss on hedges," as the case may be. It may be considered that any profit or loss on hedging could as properly be charged or credited to the grain against which it applies, but, as it is important to know just how much the hedging of grain costs, it is much better to carry a "profit and loss on hedges" account until the end of the year, when this account may be written off to the several grain accounts if desired.

RECORD OF SALES TO ARRIVE.

Under the description of the system (p. 6) will be found sufficient information regarding this form (Form No. 6; see p. 21), for, as it is only an auxiliary record for memorandum use, it has very little to do with the operation of the system.

PATRONAGE LEDGER.

At convenient periods during the year reference should be made to the grain checks and to the sales tickets, and the amount of merchandise recorded thereon, both in purchases and sales, should be posted to the patronage ledger (Form No. 7; see p. 22), under the account of the customer with whom the transaction was held. It is essential only that this material be compiled by the end of the year, so that proper reference may be made to it as the basis for paying patronage dividends. Each customer's account is totaled and the rate of dividend per bushel or per pound is entered in the upper right-hand corner. Using this ledger as a basis, checks for the amount to which each customer is entitled can be made out, and dividends distributed accordingly.

GRAIN REPORT.

The grain report (Form No. 8; see p. 23) is designed to keep the manager and directorate in close touch with the condition of their grain stock at the end of any month, or, in fact, at any time at which additions of the various entries on the grain forms may be made.

Assuming that an elevator starts its current year with a certain balance of grain on hand, as shown by the inventory, at the end of the first month, by adding "receipts this period" to "balance last report," the result will be "gross on hand." By deducting from this the "shipments and sales this period," the difference will be the "net grain stock on hand." It is always important for a manager to know whether the grain which he has on hand belongs to the elevator in whole or in part, or is partly or entirely stored grain. By subtracting the gross amount of bushels of grain purchased from the gross receipts the total amount stored at date will be shown. Should this be greater than the net on hand, it will indicate that some grain which has been stored has been sold without being purchased from the owner of the grain—in other words, that there has been an amount of stored grain sold. Should the total stored at date be less than the net on hand, then the difference between the two would be the amount of purchased grain on hand.

MERCHANDISE REPORT.

The merchandise report (Form No. 8; see p. 23) serves merely as an inventory, giving the total on hand at the last inventory, purchases, sales, and net on hand, which should agree, allowing for proper deductions or additions, with the actual inventory.

CASH, JOURNAL, PURCHASE, AND SALES RECORD.

The cash, journal, purchase, and sales record (Form No. 1, facing p. 20) differs from ordinary books of first entry in that both the debit and credit entries, which are to be posted later to the ledger, are of necessity entered on this form before it can be balanced.

The debit columns of this form are designated as follows:

Date.
Folio.
Cash.
Bank deposits.
General ledger.
Accounts receivable ledger.
Hard coal (lbs. ...., amount ....).
Soft coal (lbs. ...., amount ....).

There are also provided four columns in blank which may be used to suit the convenience and requirements of the individual elevator.

The credit columns comprise the following:

Check number.
Folio.
Bank withdrawals.
General ledger.
Accounts receivable ledger.
Sales ticket number.
Hard coal (lbs. ...., amount ....).
Soft coal (lbs. ...., amount ....).
Miscellaneous grain (lbs. ...., amount ....).

There are also blank columns to be used as desired.

A column is provided between the debit and credit sides, marked "Items," in which are written all items and an explanation of them.

DEBIT COLUMNS.

CASH.

In order that an accurate check may be had upon the amount of money received so that an identical amount may be deposited each day, all cash receipts of whatever nature should be entered in the "cash" column. These entries are footed daily and represent the amount of the deposit and are not carried forward during the month, all deposits being set down in the "bank deposits" column as the deposit is made.

BANK DEPOSITS.

In some instances where drafts are drawn directly against commission companies by the bank the money is not received at the elevator, and in such cases the deposit of drafts may be made directly into the "bank deposits" column. In this way the "bank deposits" column would include the total receipts at the elevator plus all receipts of drafts at the bank, and the total of this column carried forward during the month should equal the sum of the deposits in the bank pass book.

GENERAL LEDGER.

The "general ledger" column is provided for entry of all items to accounts in the general ledger for which no special columns are provided, and postings should be made in detail from this column to accounts in the general ledger.

ACCOUNTS RECEIVABLE LEDGER.

The accounts receivable ledger carries items for all local accounts receivable, and items in this column are posted in detail to accounts in the accounts receivable ledger.

PURCHASES.

Under the heading "Purchases" will be found columns designated "hard coal," "soft coal," etc., in pounds and amounts. All purchases of merchandise of this character are entered in their proper columns under this heading, and the totals only are posted at the end of the month to their respective accounts in the general ledger.

CREDIT COLUMNS.

The "check number" column accommodates the numbers of all checks drawn for expense and general accounts other than grain checks. The "bank withdrawals" column records the amounts of these checks. In this column is also entered the total of the grain

checks drawn during the month. The "general ledger" and "accounts receivable" columns serve the same purposes on the credit as were explained on the debit side.

LOCAL SALES.

As all the sales tickets are numbered consecutively, their numbers are listed in the "sales number" column, and the merchandise in pounds and amount is entered in the proper column to the credit of the account to which it belongs, such as "hard coal," "soft coal," "flour," etc. These columns are totaled at the end of the month and the totals only are posted to the accounts in the general ledger. Only the items which are posted from the general ledger, accounts receivable ledger, and the miscellaneous columns are listed in detail, all other columns, both debit and credit, being posted as totals. At the beginning of the month the first entry to be made on this form is "cash balance," and this should be set down in the "bank deposit" column as an amount carried forward. Because of the fact that every debit has a corresponding credit, the two sides of this form should always be in balance, but the fact that we have carried forward the cash balance, which appears on one side only, must be taken into consideration. In order that the form should foot and prove correctly, it should always be out of balance by the exact amount of the cash entry at the beginning of the month.

THE LEDGER.

The ledger should be divided into two general divisions—one carrying general accounts and the other accounts receivable—and may be designated under the headings "General ledger" and "Accounts receivable ledger." In the general ledger will be found such accounts as: (1) Cash, which is the monthly balance as shown by the cashbook; (2) "accounts receivable control" account, to which are posted debit and credit totals in the "accounts receivable" columns in the cash, journal, purchase, and sales record, the individual items having been posted previously to the accounts receivable ledger. This account serves as a proof of the correctness of such individual postings. (3) Bills receivable, including all promissory notes, time notes, bills of exchange, or acceptances receivable.

It has been the practice in some elevator accounting systems to show a subdivision of expense in the journal, but the small number of items of this character is much better taken care of through a subdivision of the ledger accounts. An ordinary ledger page may be ruled by the bookkeeper into seven or eight columns, and, as entries to expense in most cases are debit items, no credit columns need be provided. When credits occur they should be posted in red

ink and deducted in the addition of the items in the column. The several columns of the expense account may be headed "Salaries;" "Telephone, telegraph, and electric light;" "Taxes;" "Gasoline;" "Repairs;" and "Miscellaneous," or similar headings suitable to the nature of the expenses incurred.

An account should be provided showing the capital stock outstanding or the portion of the net capital which is used or is available for the working of the business.

Separate accounts should be opened for each kind of grain handled, showing the amount and value of grain purchased on the debit, and the amount and value of grain sold on the credit. At the end of the year, by crediting these accounts with the inventory of the kind of grain specified, the net profit on each kind of grain may be determined. In the case of local sales of grain, it is advisable to open separate accounts so that a clear record may be kept of the amount of grain sold locally, as well as in car lots. These local sales accounts should be closed into the general grain accounts at the end of the year.

During the course of a shipping season a considerable number of claims will arise against railroads for losses of grain in transit. Two accounts should be opened to accommodate this condition: A debit account—claims against railroads for leakage in transit, and a credit account—loss and recovery on grain leakage in transit. These accounts operate after the following manner: When a car is reported short a certain number of bushels under that recorded by the elevator's automatic scale, a charge is put through against the railroad responsible in the first-named account, and a corresponding credit is carried to the latter account. When recovery is received by remittance from the railroad company, the company is credited with the amount of the check. If the check does not cover the full amount of the claim, and no further action is to be taken looking toward its collection, then a journal entry for the remainder should be passed, crediting the account of the railroad in the claims account and debiting loss and recovery on grain leakage in transit. This latter account constitutes an income account and may be written off direct to profit and loss; or if the composition of the account is known, the specific items applying to certain kinds of grain may be credited to the grain accounts.

The following entries in the cash, journal, purchase, and sales record will serve to illustrate the method of accounting for loss and recovery on grain leakage in transit. When the grain is reported lost, the first entry to be made is as follows:

Debit Claims (B. & M. Railroad)	25.00	
Credit Loss and recovery on grain leakage in transit		25.00

After negotiations with the railroad, assume that settlement by an allowance of $15.00 is received by check. Entry would then be

made of the check showing "Cash debit $15.00," and "B. & M. Railroad credit $15.00." This leaves a credit of $25 to the account for loss and recovery on grain leakage in transit, and a debit to the railroad of $10.

Considering that the transaction has been definitely settled, and that no further recovery can be made, the following journal entry should be passed:

Debit Loss and recovery on grain leakage in transit	10.00	
Credit Claims B. & M. Railroad		10.00

This simply closes the railroad account, and leaves a balance in the loss and recovery on grain leakage in transit representing the true amount of recovery.

THE COST ANALYSIS.

The cost analysis (Form No. 15; see p. 30) has been provided to furnish information affecting the unit and relative cost of handling grain and merchandise. The method of operation is as follows:

Opposite "Bushels of grain handled" should be set down, first, the total of all grain taken into the elevator, this amount being extended under the different kinds of grain as shown by the footings of the record of grain receipts, the total grain taken in being 100 per cent. The relative percentage of each kind of grain is then set down opposite the per cent mark under the column designated. On the same line should be added the value of coal and merchandise sales.

After taking out an amount which would seem to be sufficient for the selling of merchandise, the different kinds of expense applying generally to all kinds of grain and merchandise, such as salary, insurance, interest, power, and repairs, are then prorated according to the grain percentages. This amount will be, necessarily, more or less of an estimate, but a manager, by keeping account of the time spent on coal and merchandise sales in the space of a month, can arrive at a fair basis for the division of salaries. Insurance, interest, repairs, and miscellaneous, relating to merchandise, are contained in a few items and can be easily ascertained.

Such items as "Power operating" apply only to grain. "Corn shelling—direct labor" includes only that labor which has been procured especially for corn shelling, and would not include the manager's or assistant manager's time, as their wages are prorated under "Salaries." Car cooperage should be distributed according to the amounts of grain received, except in cases where an account has been kept in the ledger showing the exact amount of cooperage against each kind of grain.

After having prorated the different expense items, the addition of these gives the gross expense. Returns from storage and returns from dockage sold are then set down under the kinds of grain which have furnished these returns, and subtracted. Any returns from

cobs sold are subtracted from cob corn. The net expense is then ascertained from these subtractions.

The total net expense being 100 per cent, the percentage of net expense of each kind of grain and merchandise will be determined as being the relative percentage of each to the total. The net unit cost of operation is determined by dividing the amount of expense by the number of bushels handled. The net unit cost in this operation would be in terms of cents or decimals of a cent. In the case of sales of coal and other merchandise the net unit cost of operation is represented by a certain percentage, as, for instance, 5 per cent of the gross sales, this percentage being determined by dividing the net expense by the value of goods sold.

BALANCING CASH WITH THE BANK.

To determine the correctness of the cash transactions for the month the following method will be found simple and adequate:

(1) Determine whether the "bank deposit" column agrees with the bank pass book as to individual deposits. Be sure that it is correctly footed.

(2) Sort the returned vouchers, arranging them consecutively. Compare them with the entries in the "bank withdrawals" column and ascertain which, if any, are missing. List the numbers and amounts of all outstanding checks for the next month's reference. Outstanding checks may be listed either on an adding-machine tape or by writing them into the cashbook. The difference between the "bank deposits" and "bank withdrawals" columns, plus the total of outstanding checks, should equal the balance as shown in the bank pass book. No error, however small, should be ignored in balancing cash with the bank.

RESERVE ACCOUNTS.

RESERVE FOR DEPRECIATION ACCOUNT.

In order to show the true condition of the plant a reserve for depreciation account is essential. To this account should be credited annually a certain percentage of the money invested in the plant, and an equal amount should be written off profit and loss.[1]

RESERVE FOR BAD DEBTS ACCOUNT.

During the operation of a business where credit is given to a large number of customers there is likely to be a loss on account of uncollectible debts. This amount may be small one year and large another. For that reason it is well to set aside a sufficient amount of capital from the yearly profits to offset such losses. To effect this, "reserve for bad debts" should be credited and "profit and loss" debited with

[1] For further explanation of reserve for depreciation see U. S. Department of Agriculture Bulletin No. 178, "Cooperative Organization Business Methods."

an amount which experience would dictate is sufficient to take care of the uncollectible debts of the company.

While many elevator companies make a practice of furnishing supplies to members and others on credit, all supplies, if possible, should be handled on a strictly cash basis. Any system of extending unprotected credit requires a large capital and often results in considerable loss.

RESERVE FOR SINKING FUND.

In some States, notably South Dakota, where the cooperative law is in operation, a statutory regulation requires that a certain percentage of the capital invested be set aside each year in a reserve for sinking fund, so that the company will be in a position to retire its capital stock at the end of a given period. Companies operating under such conditions should set up a reserve for sinking fund in accordance with the requirements of their State laws.

Where the custom of hedging grain prevails, an account should be opened designated "profit and loss on hedging." To this should be debited or credited the losses or gains incident to the hedging of grain, the opposite entry being made to the commission account handling the business.

To determine the profit and loss for the year, all income accounts should be credited and all expense accounts debited to this account. When the amount of profit has been ascertained, dividends may be declared and paid, and the remainder transferred to the surplus account.

After the books have been closed for the year, any errors discovered affecting the previous year's business should be entered in the account affected and carried to the opposite side of the surplus account, the profit and loss account being reserved for the current year's business.

The individual needs and the peculiar conditions surrounding elevators in different parts of the United States may require other accounts besides those discussed above, and if such is the case, accounts covering these special requirements may be opened along the same general lines as those previously discussed.

The following balance sheet is submitted as a guide in the arrangement of assets and liabilities. Other asset and liability accounts may appear on the books of an elevator and in such case should be included.

STATEMENT.

FARMERS' ELEVATOR BALANCE SHEET, YEAR ENDING ....

ASSETS.

Cash		$287.50
Accounts receivable	$3,208.00	
Less reserve for bad debts	400.00	
		2,808.00
Notes receivable		325.00
Plant and real estate	9,500.00	
Less reserve for depreciation	1,300.00	
		8,200.00
Grain commission accounts		860.00
Inventory:		
Wheat	1,458.00	
Corn	395.00	
Oats	536.00	
Rye	28.00	
Barley	106.50	
Hard coal	281.00	
Soft coal	354.00	
Other merchandise (supplies)	2,976.70	
		6,135.20
		18,615.70

LIABILITIES.

Accounts payable	876.55
Notes payable	4,200.00
Capital paid in	8,950.00
Surplus	4,589.15
	18,615.70

SUPPLY ACCOUNTS SETTLED WITH GRAIN.

When requests are received from patrons to deduct from the amount due for grain sold the amount which they may owe the company for supplies purchased, two grain checks should be issued. The first check should contain the total number of bushels and kind of grain being purchased, together with the balance due the patron after deducting the amount of his account from the full value of the grain.

A second check should then be made without reference to bushels of grain, and marked "For a/c receivable," in the full amount deducted from the previous check. This check is then indorsed over to the elevator by the patron and both checks are entered in the record of grain purchases, the first check going to the patron and the second being deposited to the account of the elevator as cash received. By this means both sides of the transaction have been carried out through the only proper medium of settling accounts, *which is cash.*

FILING STORAGE AND SALES TICKETS.

Another method of compiling records as a basis for the distribution of patronage dividends, which is in operation in some of the elevators where the Office of Markets and Rural Organization has installed its system of elevator accounting, may be recommended for its convenience.

Under this method suitable drawers are divided into two compartments each by transverse partitions. Each front compartment should be of about one-fourth the size of the drawer. The back compartment is then fitted with an A-B-C index conforming in height with the material to be indexed. Two drawers of this description or a drawer divided into four compartments on the same basis will be necessary.

In one drawer are filed the storage tickets and in the other the sales tickets. In some States, where no grain is taken in storage, grain-purchase tickets are issued by the elevators, which bear, in addition to the usual information contained on a storage ticket, the items of price and value of grain. These purchase tickets are contracts to buy at a certain price, but for the purposes of this compilation of information they may be considered technically as storage tickets. The general term "storage ticket" will therefore be used in the discussions of both of these forms. All storage and sales tickets not paid for are filed consecutively according to number in the front compartment of the drawer designated for each. This should be done daily.

As checks are issued for grain and payments received against sales the tickets of each kind covered by these cash transactions are taken from the numerical file and then are placed in the A-B-C file under the name appearing at the top of the ticket.

It often happens that a storage ticket is issued under the name of one owner when in reality it is subject to joint ownership, and this fact would seem to make proper filing difficult. Before purchase by the elevator, however, the true condition of ownership appears.

As each owner is paid for his share, a slip bearing the original ticket number and giving the name of the owner, the bushels, and the kind of grain is filed under the proper letter. A notation is made on the original ticket of this deduction, and when the last owner to settle appears the original is filed under his name. Up to the point of final settlement the original ticket is held in the numerical file.

At the end of the year the A-B-C file will contain all the completed transactions grouped according to patrons' names. By use of an adding machine a complete list of the data upon which dividends are to be paid can be compiled in a few hours.

Using this method of filing as a basis the tickets may be entered individually in the patronage ledger or, where conditions permit, the

adding-machine totals (which should first be verified) may constitute the only entry in the patronage ledger, thus saving a considerable amount of clerical labor without detracting from the accuracy of results.

For the convenience of those interested in the system described in this bulletin and for those who desire to have the system printed, the Office of Markets and Rural Organization has provided printer's copy of the several forms for free distribution.

All elevators installing the system of accounts may refer to this office any questions regarding its installation or operation.

A sectional post transfer binder has been found convenient and adequate for binding the accounting forms. The standard size is, length over all, 15½ inches, width 10½ inches, posts five-sixteenth inch in diameter and 7 inches from center to center.

CONCLUSION.

The foregoing pages outline very briefly certain information regarding operating grain elevators, and in particular describe the methods used in operating a system of grain elevator accounting. But the simple keeping of the records is not sufficient. To obtain benefits commensurate with the opportunities open in the field of cooperative grain elevators, the manager and directors of the elevators possessing such an accounting system should make use of all the information which it is able to furnish. If there is a common knowledge among the stockholders that the business of the elevator is being handled in a competent manner, and that details and statistics regarding it can be furnished at any time, it will act as a bond of faith and will secure the loyalty of the members to their organization.

ᐧURCHASE, AND SALES RECOI

ural Organization, Grain System Form No. 1

Date.		Items.	Local sales.									
				Flour.		Miscel. grain.						
				Amount.		Lbs.	Amount.		Lbs.	Amount.		
1914.												
ec.	1	*Balance in bank Dec. 1*										
"	1	*James Goodhue*										
"	1	*Cash sale (Goodhue)*										
"	1	*" " (J. G. Nord)*										
"	2	*Lipsey & Co.—by draft*										
"	2	*" " —balance by check*										
"	3	*Illinois Coal Co., car 69851*										
"	4	*T.P. & W. Rwy., freight car 96103*										
"	8	*Cash sale—Oats*				96	1	20				
"	9	*" " Corn*				280	3	00				
"	9	*" " Flour*	0	8	00							
"	9	*" " Corn*				280	3	00				
"	12	*Bruno & Co., letterheads*										
"	13	*James Goodhue on %—Check*										
"	15	*G. J. Ivan, advance*										
"	21	*Lehigh Coal Co., car 8693*										
"	25	*R. A. Smith, repairs and cooperage*										
"	29	*J. C. Nicholson, Dec. salary*										
"	29	*C. D. Haywood, " "*										
"	31	*Total grain checks, Dec.*										
		Wheat %										
		Durum %										
		Barley %										
		Oats %										
		Rye %										
		Flax %										
		Corn %										
ec.	31	*H. L. Hankinson & Co*										
		To profit on hedges										
"	31	*Lipsey & Co., drafts*										
		Footings	0	8	00	656	7	20				

eous columns posted to their various accour

CASH, JOURNAL, PURCHASE, AND SALES RECORD.

Office of Markets and Rural Organization, Grain System Form No. 1.

Purchases.																						Local sales.											
			Flour.		Soft coal.		Hard coal.		Accounts receivable.	General ledger.	Bank deposits.	Cash.	Folio.	Date.	Items.	Check No.	Folio.	Bank withdrawals.	General ledger.	Accounts receivable.	Sale No.	Hard coal.		Soft coal.		Flour.		Miscel. grain.					
			Lbs.	Amount.	Lbs.	Amount.	Lbs.	Amount.														Lbs.	Amount.	Lbs.	Amount.	Lbs.	Amount.	Lbs.	Amount.	Lbs.	Amount.		
											2,675 80			1914. Dec. 1	Balance in bank Dec. 1																		
									14 00					" 1	James Goodhue						186	2,450	14 00										
												8 10		" 1	Cash sale (Goodhue)						187	1,280	8 10										
											14 10	6 00 14 10		" 1	" " (J. G. Nord)						188			2,200	6 00								
											1,000 00			" 2	Lipsey & Co.—by draft				1,000 00														
											236 10			" 2	" " —balance by check				236 10														
					80,460	86 40								" 3	Illinois Coal Co., car 69851	101		86 40															
						67 20								" 4	T.P. & W. Rwy., freight car 96103	102		67 20															
												1 20		" 8	Cash sale—Oats						189							96	1 20				
												3 00		" 9	" " Corn						190							280	3 00				
												8 00		" 9	" " Flour						191					200	8 00						
											15 20	3 00 15 20		" 9	" " Corn						192							280	3 00				
										12 50				" 12	Bruno & Co., letterheads	103		12 50															
											20 00			" 13	James Goodhue on %—Check					20 00													
									100 00					" 15	G. J. Ivan, advance	104		100 00															
							68,500	165 50						" 21	Lehigh Coal Co., car 8693	105		165 50															
										15 10				" 25	R. A. Smith, repairs and cooperage	106		15 10															
										110 00				" 29	J. C. Nicholson, Dec. salary	107		110 00															
										50 00				" 29	C. D. Haywood, " "	108		50 00															
														" 31	Total grain checks, Dec.			5,010 25															
										612 50					Wheat %																		
										172 20					Durum %																		
										189 45					Barley %																		
										133 80					Oats %																		
										59 85					Rye %																		
										63 00					Flax %																		
										3,779 45					Corn %																		
										18 50				Dec. 31	H. L. Hankinson & Co																		
															To profit on hedges				18 50														
											3,000 00			" 31	Lipsey & Co., drafts				3,000 00														
					80,460	153 60	68,500	165 50	114 00	5,216 35	6,961 20				Footings			5,616 95	4,254 60	20 00		3,730	22 10	2,200	6 00	200	8 00	656	7 20				

Individual items in general ledger. Accounts receivable and miscellaneous columns posted to their various accounts in ledger. Post totals only in all other cases.

EIPTS.

System Form No. 2.

Date.	Rye. Dockage.	Rye. Net.	Flax. Gross.	Flax. Dockage.	Shelled corn. Grade 4.	Shelled corn. Grade 5.	Shelled corn. Grade 6.
1914. Dec.							
"							
"							
"							
"	2	98					
"							
"							
"							
"							
"							
"							
"			50	5			
"							
"							
"							
"							
"							
"							
"							
"							
"							
"							
"							
"							
"							
"		60					
"							
"							
"							
"					823 40		
"					1,254 16		
"							
0	2 00	158 00	50 00	5 00	2,078 00		

ng provided if necessary.

RECORD OF GRAIN RECEIPTS.

Office of Markets and Rural Organization, Grain System Form No. 2.

Date.	Storage ticket No.	Paid by check No.	Wheat.							Durum.			Barley.	Oats.	Rye.			Flax.			Corn on cob.		Shelled corn.					
			Gross.	Dockage.	No. 1.	No. 2.	No. 3.	No. 4.	Reject.	Gross.	Dockage.	Net.	Net.	Net.	Gross.	Dockage.	Net.	Gross.	Dockage.	Net.	Grade.	Grade.	Grade 1.	Grade 2.	Grade 3.	Grade 4.	Grade 5.	Grade 6.
1914. Dec. 1	987	603	80 40	2 40		78																						
" 1	988	609	66	1	65																							
" 1	989	605	126 10	4 10			122																					
" 1	990	610	90 30	2 30		88																						
" 1	991	604													100	2	98											
" 1	992		60	1 40	58 20																							
" 2	993		78 40	2				76 40																				
" 2	994	602	70	1 30				68 30																				
" 2	995	606	104 10	3 10				101																				
" 2	996	607	65 50	2 20				63 30																				
" 2	997	Void.																										
" 3	998	608																50	5	45								
" 3	999									200 30	4 30	196																
" 4	1000									80	2 10	77 50																
" 4	1001												66 10															
" 5	1002												50 40															
" 5	1003												45 20															
" 7	1004	611											287 22															
" 7	1005	614												326 12														
" 7	1006													45 20														
" 7	1007													126 10														
" 8	1008	612											105															
" 8	1009	615	60 30	1 30	59																							
" 8	1010	613								125 20	2 20	123																
" 8	1012		80 30	2 20			78 10																					
" 9	1013														60		60											
" 9	1014	616																						563 32				
" 10	1015	617																						1,265 24				
" 10	1016	618																							745			
" 10	1017	619																								823 40		
" 11	1018	620																								1,254 16		
" 12	1019	621																						860				
			883 00	24 50	182 20	166 00	200 10	309 40		405 50	9 00	396 50	654 44	498 10	160 00	2 00	158 00	50 00	5 00	45 00				2,689 00	745 00	2,078 00		

Totals carried to the Grain Report.

If desired, additional grades under "Wheat" can be included, extra columns being provided if necessary.

All items carried in bushels, fractional bushels in pounds.

	Grade.		Grade 2.		Grade
			563	32	
			1,265	24	
					745
			860		
			2,689	00	745
			×		×

ied in bushels, fractional bushels in pc

et.		Proceeds.		Grade.		

eing provided if necessary.

RECORD OF GRAIN PURCHASES.

Office of Markets and Rural Organization, Grain System Form No. 3.

Date.	Check No.	Storage ticket No.	Price.	Amount.	Wheat. No. 1.	Wheat. No. 2.	Wheat. No. 3.	Wheat. No. 4.	Wheat. Reject.	Wheat. Storage.	Wheat. Cost.
1914. Dec. 1	603	587	1.07	[illegible].45		78					87 45
" 1	604	991	.57	59.85							
" 2	605	989	1.05	128.10			122				128 10
" 4	606	995	1.00	101.00				101			101 00
" 6	607	996	1.00	63.50				63 30			63 50
" 7	608	998	1.40	63.00							
" 7	609	988	1.12	71.80	65						71 80
" 7	610	990	1.10	96.80		88					96 80
" 8	611	1004	.48	138.00							
" 8	612	1008	.49	51.45							
" 8	613	1010	1.40	172.20							
" 8	614	1005	.41	133.80							
" 8	615	1009	1.15	67.85	59						67 85
" 10	616	1014	.69	388.85							
" 10	617	1015	.69	873.20							
" 26	618	1016	.68	506.60							
" 28	619	1017	.67	552.00							
" 30	620	1018	.69	865.40							
" 31	621	1019	.69	593.40							
				5,010.25	124	100 00	122	164 30			612 50
				√	×	×	×	×			√

Date.	Durum. Net.	Durum. Storage.	Durum. Cost.	Barley. Net.	Barley. Storage.	Barley. Cost.	Oats. Net.	Oats. Storage.	Oats. Cost.	Rye. Net.	Rye. Storage.	Rye. Cost.	Flax. Net.	Flax. Storage.	Flax. Cost.
1914. Dec. 1															
" 1										98		59 85			
" 2															
" 4															
" 6															
" 7													45		63 00
" 7															
" 7															
" 8				287 22		138 00									
" 8				105		51 45									
" 8	123		172 20												
" 8							326 12		133 80						
" 8															
" 10															
" 10															
" 26															
" 28															
" 30															
" 31															
	123		172 20	392 22		189 45	326 12		133 80	98 00		59 85	45 00		63 00
	×		√	×		√	×		√	×		√	×		√

Date.	Corn on cob. Grade.	Corn on cob. Grade.	Corn on cob. Cost.	Shelled corn. Grade.	Shelled corn. Grade 2.	Shelled corn. Grade 3.	Shelled corn. Grade 4.	Shelled corn. Grade.	Shelled corn. Grade.	Shelled corn. Cost.
1914. Dec. 1										
" 1										
" 2										
" 4										
" 6										
" 7										
" 7										
" 7										
" 8										
" 8										
" 8										
" 8										
" 8										
" 10					563 38					388 85
" 10					1,265 24					873 20
" 26						745				506 60
" 28							823 40			552 00
" 30							1,254 16			865 40
" 31					860					593 40
					2,080 00	745 00	2,078 00			3,779 45
					×	×	×			√

√=Carried to cash journal. ×=Carried to grain report. If desired, additional grades under "wheat" can be included, extra columns being provided if necessary. All items carried in bushels, fractional bushels in pounds.

RECORD OF GRAIN SHIPMENTS AND SALES.

Office of Markets and Rural Organization, Grain System Form No. 4.

Date.	Shipped to—	Car No.	Weight.	Date sold.	Price.	Net proceeds.	Folio.	Wheat. Gross.	Wheat. Dkg.	Wheat. No. 1.	Wheat. No. 2.	Wheat. No. 3.	Wheat.	Wheat. Proceeds.	Durum. Gross.	Durum. Dkg.	Durum. Net.	Durum. Proceeds.
1914. Dec. 1	Lapsey & Co.	N. P. 9912	1,200	1914. Dec. 15	1.09	1,245 25	√	1,210	23		1,187			1,245 25				
" 5	" "	T. P. W. 9650	1,250	" 24	1.11[illegible]	1,310 60	√	1,250	10	1,240				1,310 60				
" 9	" "	T. P. W. 12962	1,020	" 30	1.35	1,352	√								1,330	26	1,304 00	1,352
						3,907 75		2,460	33	1,240	1,187			[illegible] 75	1,330	26	1,304 00	1,352
" 21	Dalrymple Grain Co.	Penn. 1526	1,400															
" 30	Beach Wickem Grain Co.	G. R. 9994	1,350	1915 Jan. 10	.72	826 30	√											

Date.	Barley. Net.	Barley. Proceeds.	Oats. Net.	Oats. Proceeds.	Rye. Gross.	Rye. Dockage.	Rye. Net.	Rye. Proceeds.	Flax. Gross.	Flax. Dkg.	Flax. Net.	Flax. Proceeds.	Shelled corn. Grade.	Shelled corn. Grade 2.	Shelled corn. Grade.	Shelled corn. Grade.	Shelled corn. Grade.	Shelled corn. Grade.	Shelled corn. Proceeds.
1914. Dec. 1																			
" 5																			
" 9																			
" 21																			
" 30														1,328					826 30

Net proceeds to be debited to grain dealers, and proceeds of each variety of grain to be credited to grain accounts in general ledger, posting to be made direct.
Amount of bushels to be carried to grain report.

If desired, additional grades under "Wheat" can be included, extra columns being provided if necessary.
All items carried in bushels, fractional bushels in pounds.

RECORD OF HEDGES.

Office of Markets and Rural Organization, Grain System Form No. 5.

Futures bought.							P. & S. accounts.			Futures sold.							Remarks.
Date.	Bushels.	Market.	Bought from.	Month.	Kind.	Price.	Dr.	Cr.	Folio.	Date.	Bushels.	Market.	Sold to.	Month.	Kind.	Price.	
1914. Dec. 6	*1,000*	*Mpls*	*W. C. M. Co.*	*May*	*2 wht*	*109*		*18 50*	*J. 1*	*Dec. 16*	*1,000*	*Mpls*	*Dalrymple.*	*May*	*2 wht*	*1.11*	*Dr. Hankinson, 18.50.*
Dec. 22	*2,000*	"	*Hankinson*	"	*3* "	*108*											

RECORD OF SALES TO ARRIVE.

Office of Markets and Rural Organization, Grain System Form No. 6.

Date.	Bushels.	Kind.	Grade.	Price.	Delivery date.	Sold to—	Cars applied.	Shippers' weight.	Date shipped.	Date received.	Destination grade.	Destination weight.	Remarks.
1914.					*1915.*				*1914.*	*1914.*			
Dec. 1	*3,000* —	*Wht. corn*	*3*	*64*	*Jan. 10*	*Dipsey & Co., Chicago.*	*A. 96542*	*1,456* —	*Dec. 8*	*Dec. 12*	*3*	*1,445*—	
							A. 89625	*1,250* 2706 —	" *21*	" *23*	*3*	*1,254*—	
Dec. 15	*5,000* —	*Yel. corn*	*4*	*58*	*Febry. 1*	*Beach Wickem Grain Co., Peoria.*	*T. P. W. 9685*	*1,600* —	*Dec. 21*	*Dec. 30*	*3*	*1,600*—	*Premium 1¢.*
									1915.	*1915.*			
							T. P. W. 5462	*1,200* —	*Jan. 7*	*Jan. 10*	*4*	*1,210*—	
							T. P. W. 8625	*1,320* 4120 —	" *23*	" *26*	*4*	*1,310*—	

PATRONAGE LEDGER.

Office of Markets and Rural Organization Grain System Form No. 7.

Name: *James Goodhue.*

Rate, *3¢* per bu.
Rate, *1¢* per lb.

Sales.																	Purchases.													
Check No.	Wheat.		Durum.		Barley.		Oats.		Rye.		Flax.		Corn.		Live-stock.		Sales No.	Hard coal.		Soft coal.		Flour.		Grain.						
603	*78*	—															*186*	*24*	*50*											
609	*65*	—															*187*	*12*	*80*											
610	*88*	—															*199*	*14*	*10*											
611					*286*	*70*											*325*			*24*	*12*									
614							*326*	*12*									*403*			*14*	*80*									
	231	—			286	70	326	12																						
																	409			*22*	*10*									
																	512			*25*	*50*									
																		51	40	86	52									

GRAIN REPORT.

Office of Markets and Rural Organization, Grain System Form No. 8.

Date.........................., 191..

	Wheat.		Durum.		Barley.		Oats.		Rye.		Flax.		Corn on cob.		Shelled corn.	
	Bushels.	Value.	Bushels.	Value.	Bushels.	Value.	Bushels.	Value.	Bushels.	Value.	Bushels.	Value.	Bushels.	Value.	Bushels.	Value.
Balance last report	2,830		1,300		820		2,000		185							
Receipts this period	858		397		555		498		158		45				5,512	
Gross on hand	3,688		1,697		1,375		2,498		343		45				5,512	
Shipments and sales	2,427		1,304													
Net on hand	1,261		393		1,375		2,498		343		45				5,512	
Gross on hand	3,688		1,697		1,375		2,498		343		45				5,512	
Gross purchased	576		123		392		326		98		45				5,512	
Total stored at date	3,112		1,574		983		2,172		245							

NOTE.—Stored wheat and durum exceed net on hand, indicating stored grain sold.

MERCHANDISE REPORT.

	Hard coal.		Soft coal.		Flour.		Feed.		Posts.							
	Amount.	Value.	Amount.	Value.	Amount.	Value.	Amount.	Value.	Amount.	Value.	Amount.	Value.	Amount.	Value.	Amount.	Value.
On hand last inventory																
Purchases																
Total																
Sales																
Net on hand																

FARMERS' COOPERATIVE ELEVATOR COMPANY.

Office of Markets and Rural Organization, Grain System Form No. 9.

MANAGER'S REPORT.

Report No.......... At.......................... Date from................to...............

Grain receipts.						Grain purchases.								
Date.	Ticket number.	Kind and grade.	Gross.	Dockage.	Net.	Date.	Check number.	Ticket number.	Amount of check.	Kind and grade.	Net bushels.	Price.	Grain cost.	Storage.

This report includes

Scale tickets No............to............ Cash receipts No............to...........

GRAIN CHECK.

Office of Markets and Rural Organization, Grain System Form No. 10.

.... No. ......

Pay to the order of .... $.........

.... $\frac{}{100}$ Dollars.

Bu. of—	Amount.	
Deduction for	....	....
Amount of check..................	....	....

This check is given for full value of grain, subject to the deductions as stated hereon.

.............................., *Manager*.

.... Bank.

Of..........................

WAREHOUSE SCALE TICKET.

Office of Markets and Rural Organization, Grain System Form No. 11.

No............. ...., 191

.... Co.

At ....

This ticket is not a storage ticket and is not negotiable. Is must be exchanged on day of issue for a lawful storage ticket or cash check.

Owner ....

Driver.................................. On.................. Off...............

Load of ....

Grade.................................. Dockage Lbs. ....

Signed .... Agent.

Exchanged for Check No. ...., Storage Ticket No. ....

Pounds.			Bushels.		
Gross.	Tare.	Net.	Gross.	Dockage.	Net.

STORAGE TICKET.

Office of Markets and Rural Organization, Grain System Form No. 12.

Storage ticket No.	Gross.	Tare.	Net.
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....

No. ......

FARMERS' ELEVATOR COMPANY.

At............................., 191...

Received of..

Bushels......................Grade......................Dock..................Grain..................
which amount, kind, and grade of grain will be delivered to the holder of this receipt, or his order, upon surrender thereof, subject to the conditions and charges stated on the back of this receipt.

............bu., ...lbs. gross.
............bu., ...lbs., dockage.
............bu., ...lbs., net.

FARMERS' ELEVATOR COMPANY,
Per ....

On the back of this form should be printed the rates of storage and the conditions affecting storage of grain as provided by laws in the State in which the elevator is situated.

Office of Markets and Rural Organization, Grain System Form No. 13.

No. ....

SALES TICKET

Of ....

At ....

Sold to .... Date ....

Hard Coal.

Gross...........................	....	....
Tare...........................	....	....
Net...........................	....	....
Total hard coal..............	....	....

Soft Coal.

Gross...........................	....	....
Tare...........................	....	....
Net...........................	....	....
Total soft coal..............	....	....

Miscellaneous.

....	....	....
....	....	....
....	....	....
Total miscellaneous..........	....	....
Total sales..................	....	....

Office of Markets and Rural Organization, Grain System Form No. 14.

CASH RECEIPT

No. ....

By ....

Received from .... Date, ..., 191..

For—	Amount.	

FARMERS' ELEVATOR CO. OF ....

COST ANALYSIS.

Office of Markets and Rural Organization, Grain System Form No. 15.

Year ending *December 31, 1914.*

	Total.	Wheat.	Durum.	Barley.	Oats.	Rye.	Flax.	Cob corn.	Shelled corn.	Sales coal.	Sales other merchandise.
	100%	33.2%	21.0%	9.3%	8.3%	.7%	.3%	.6%	26.6%	Value.	Value.
Bushels of grain handled	380965	126400	80192	35400	31633	2468	1240	2000	101632	2848 60	4286 80
Salaries	2200 00	693 88	438 90	194 37	173 47	14 63	6 27	12 54	555 94	43 89	66 11
Insurance	725 00	199 20	126 00	55 80	49 80	4 20	1 80	3 60	159 60	49 88	75 12
Interest	180 00	59 76	37 80	16 74	14 94	1 26	54	1 08	47 88		
Power, operating	226 80	75 30	47 63	21 09	18 82	1 59	68	1 36	60 33		
Corn shelling—direct labor	4 80							4 80			
Repairs	475 00	148 41	93 87	41 57	37 10	3 13	1 34	2 68	118 90	10 00	18 00
Cooperage, cars	125 00	41 50	26 25	11 63	10 37	88	37	75	33 25		
Miscellaneous	785 46	245 68	155 40	68 82	61 42	5 18	2 22	4 44	196 84	12 46	33 00
Gross expense	4722 06	1463 73	925 85	410 02	365 92	30 87	13 22	31 25	1172 74	116 23	192 23
Returns from storage	108 26	50 20	20 40	30 16	7 50						
Returns from dockage sold	345 30	211 32	133 98								
Returns from cobs sold	2 50							2 50			
Net expense	4266 00	1202 21	759 47	379 86	358 42	30 87	13 22	28 75	1172 74	116 23	192 23
Per cent of net expense	100%	28.3%	17.9%	8.9%	8.5%	.7%	.3%	.6%	27.6%	2.7%	4.5%
Net unit cost of operation		.009	.009	.013	.013	.012	.012	.014	.011	4.2%	4.5%

The figures contained in this form are intended merely as an illustration and are not based on actual figures taken from an elevator.

BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 237

Contribution from the Office of Markets and Rural Organization,
Charles J. Brand, Chief.
April 20, 1915.

STRAWBERRY SUPPLY AND DISTRIBUTION IN 1914.[1]

By WELLS A. SHERMAN, *Specialist in Market Surveys;* HOUSTON F. WALKER, *Scientific Assistant;* and O. W. SCHLEUSSNER, *Market Assistant.*

SCOPE OF THE INVESTIGATION.

Early in the spring of 1914 inquiries were addressed by the Office of Markets and Rural Organization to station agents at all points listed in the trade papers as shipping strawberries in full carloads, and to every cooperative association handling the crop, of which the department had any knowledge, asking for a record of the car-lot shipments for 1913 and an estimate of the shipments to be made in 1914. At the same time an effort was undertaken to build up a correspondents' list of persons directly interested in the commercial strawberry crop from whom reliable information on every phase of strawberry marketing could be obtained. As soon as the shipping season of 1914 was ended the inquiry was renewed and has been followed up, until this office now has definite reports on the shipments during 1914 from 466 shipping stations at which strawberries originate in car lots and a statement from the transportation or shipping agencies as to the number of carloads shipped from each.

It is the primary purpose of this bulletin to present these data for the information of the shipper, the distributor, and the consuming public, and to invite the closest scrutiny and criticism of the figures presented.

The completion of a survey of this character is found to present many difficulties, and it is fully realized that it can be perfected only as it is subjected to the criticism of the trade. Freely admitting that this compilation and the map showing graphically its most salient features can be neither absolutely complete as to shipping points nor entirely accurate as to quantity of berries moved, it is presented with confidence that it is the most comprehensive survey of the commercial strawberry crop that has ever been made, and it is believed

[1] About 95 per cent of the reports of shipments listed in this publication were furnished by railroad officials, to whom grateful acknowledgment is made for their courtesy and assistance.

NOTE.—This bulletin is of general interest to strawberry growers, shippers, dealers, transportation companies, and consumers, and to all engaged in the trade in berries and fruits.

therefore that it will be found immediately useful to the trade. It also should serve as a basis for valuable work in the future.

Coincident with the publication of this survey and map, the Office of Markets and Rural Organization is attempting to inaugurate a limited telegraphic market news service for the strawberry crop. The office expects to secure reports by telegraph from all important car-lot producing sections, giving the number of cars shipped daily during the period of important movement, together with their destination. The attempt will be made to keep this information up to date by securing the diversions as they are ordered, so that at any time the actual number of cars moving toward any one market can be readily ascertained. Acting as a clearing house for this information, this office will be able to keep competing producing areas and all consuming centers advised concerning the total car-lot shipments.

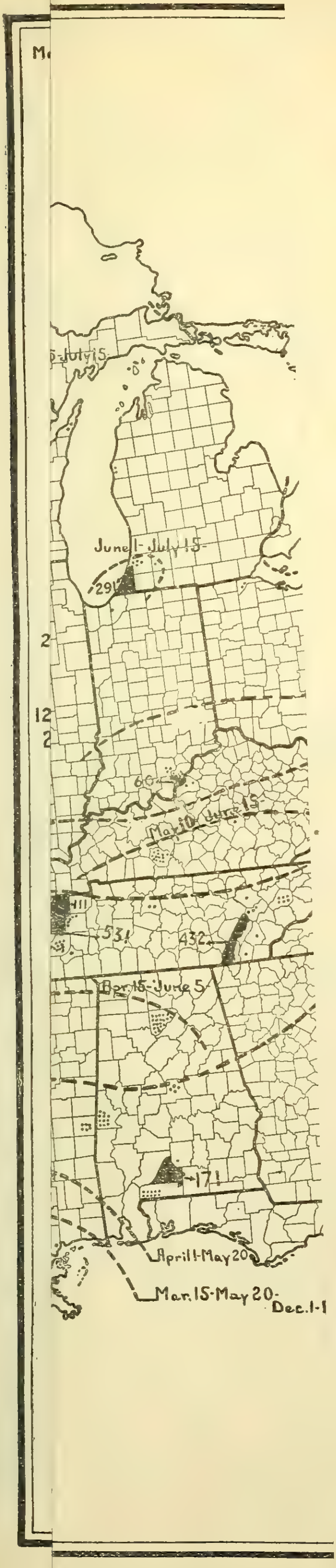
Supplementing this service on shipments, there will be daily telegrams from all the principal markets giving arrivals and prices. Arrangements have been made to secure these reports from the persons in each market most deeply interested in the strawberry deal. A summary of this market information will be telegraphed daily, collect, to every shipping association desiring the information. The complete success of this service, especially as it is extended to other crops, will depend very largely upon the continued cooperation and assistance of the transportation companies.

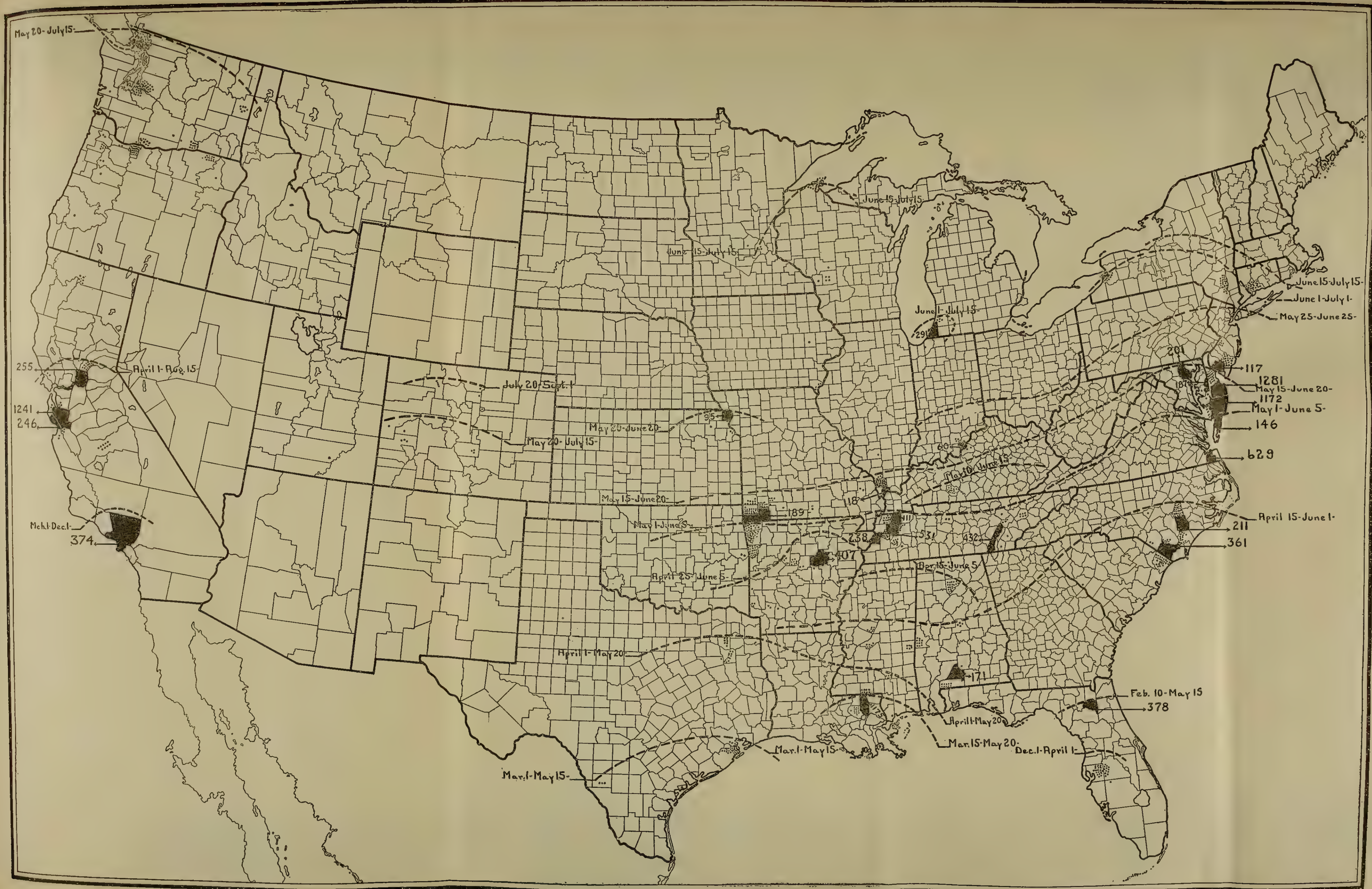
STRAWBERRY SHIPMENTS DURING 1914.

The tabulated statement which follows shows the strawberry-shipping stations and the actual number of cars shipped from each during the 1914 season. It must be kept in mind that these data cover only the 1914 shipments and that seasonal variation is so great that in some cases these figures may be far in excess or much below the usual shipments.

In some cases certain stations are credited in the tabulation with less than car-lot shipments. This is explained by the fact that these stations normally ship in full carloads, but owing to a short crop or other abnormal conditions in 1914 they did not ship their customary quantities. These figures are grouped by States and by shipping districts. Counties are ignored in the tabulation, since county lines are without significance in a survey of this kind, which is not based on census data.

In the region bordering on Chesapeake Bay, Lake Michigan, the Hudson River, San Francisco Bay, and Puget Sound shipments by boat are of considerable importance. Some difficulty has been experienced in obtaining accurate reports for these shipments. It is believed, however, that the figures for this class of shipments are fairly complete. In all such cases the quantity reported as shipped by boat has been reduced to equivalent carloads; for instance,


June 1-July 15
291
May 10-June 15
411
531
432
Apr. 15-June 5
171
April 1-May 20
Mar. 15-May 20
Dec. 1-1



Map showing actual strawberry shipments during the season of 1914

90369°—Bull. 237—15. (To face page 2.)

Benton Harbor to St. Joseph, Mich., reported 225,000 cases by boat, and this was tabulated as an equivalent of 225 carloads. The figures for the Norfolk region were obtained mainly from the various selling associations, and it is believed that they include the shipments by boat.

Our designation of the various shipping districts is arbitrary, but is believed to follow in general the custom of the trade. The point at which the largest shipments originate, or the point at which the industry first attained commercial importance, usually gives its name to the entire shipping district which later grows up around it. This is exemplified by the Independence district in Louisiana and the Judsonia district in Arkansas. These are the names best known to the trade in the markets where the bulk of these berries are handled. Experience with the proposed news service may enable a better system of designation for points of origin to be developed, but for the present the usages of the trade will be followed.

The accompanying map indicates the actual shipments in the season of 1914. Each dot represents five cars, except in counties showing only one dot, in which cases the dot may represent from one to five cars. These dots are grouped in the county in which the station is located, although it is well known that production does not actually follow the county lines. In cases where the shipments were too heavy to be represented by dots, the counties have been blacked in and the actual number of cars shipped given in figures. The size of the blackened area is not directly in proportion to the quantity shipped, as the tabulation plainly shows. This is noticeably apparent in the case of California. Thus, from the Santa Clara-Santa Cruz section approximately 1,500 cars were shipped in 1914, while from the Castleberry section but 177 cars were shipped; yet on the map the blackened areas appear equal. This apparent discrepancy arises from the necessity of treating the county as the unit when presenting data on an outline map.

The dates within which the various areas ship are shown by curved lines, all of the areas shipping at a given period being grouped into a zone under the line representing that period. Regular commercial shipments, other than from Florida, commence in March in Texas and Louisiana, gradually moving north until the season ends in July with the berries from northern Wisconsin. This statement excludes Colorado and California, where the shipping season is greatly prolonged. The map thus shows at a glance from what sections each producing area may expect the keenest competition.

This same information is illustrated in a different manner by the chart on page 5. In this chart the length of each figure from left to right shows the season in which car-lot shipments move from the district named. The areas represent graphically the number of cars shipped and are based on the figures opposite in the right-hand column.

The districts are arranged from the top to the bottom of the page according to the opening dates of the shipping seasons. By glancing down the column for each month one can see not only which districts have overlapping shipping seasons, but also the relative amounts being shipped from each district.

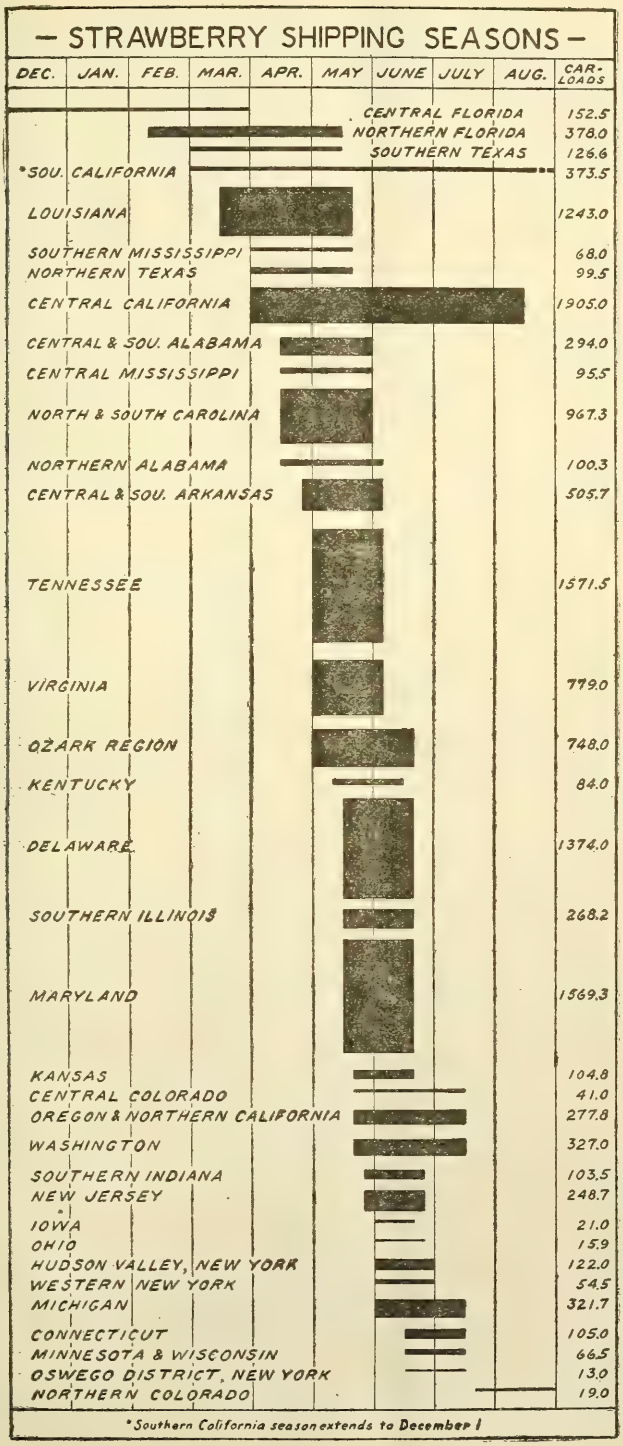
In drawing up this chart it was assumed arbitrarily that the number of cars shipped from one district was the same each week from the beginning to the end of the shipping season. Inasmuch as the shipments gradually increase from the beginning of the season until they reach a maximum at the time the bulk of the crop is moving, then gradually fall off until the end of the season, the diagram might be misleading. However, the chart shows in a general way the overlapping or competing of the different districts and forms the basis for future work of a more accurate nature.

A superficial study of the map and the tabulation might lead to an erroneous conclusion as to the relative magnitude of the strawberry industry in Northern and Southern States. It must be remembered that great quantities of berries are grown in the North in small patches and are shipped to market by trolley, by express, and by less than carload freight, while a great many go directly to the consuming centers in the producers' wagons. Comparatively few of these shipments, however, are concentrated into carloads and shipped over long distances except from the northern districts on the Pacific coast.

The chart indicates that the eight most important commercial strawberry districts in 1914 were as follows, ranked according to carload shipments: Central California, 1,905 cars; Tennessee, 1,571.5 cars; Maryland, 1,569.3 cars; Delaware, 1,374 cars; southern Louisiana, 1,243 cars; North and South Carolina, 967.3 cars; Virginia, 779 cars; Ozark region, 748 cars.

With respect to the northern cities east of the Mississippi River, it may be said in general that when they are depending on northern berries, each is to a large extent supplied by its own territory. The car-lot movement is light, and the marketing problem wholly different from that which confronts the shipper in the Carolinas or south of the Ohio River. This is one reason why the industry in the South has developed to such large proportions within very limited areas.

While no attempt has been made to list stations where no full cars originate, yet at those stations where full cars do originate the less than car-lot shipments have also been ascertained, and have been reduced to equivalent carloads, and are included in the tables here shown. Thus Jefferson County, Ky., usually ships in solid cars, but last season being an off year, no full cars went out, although less than car-lot shipments equivalent to seven cars were forwarded. As this is usually car-lot producing territory, it has been given its proper showing on the map.


– STRAWBERRY SHIPPING SEASONS –
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
CAR-LOADS
CENTRAL FLORIDA 152.5
NORTHERN FLORIDA 378.0
SOUTHERN TEXAS 126.6
*SOU. CALIFORNIA 373.5
LOUISIANA 1243.0
SOUTHERN MISSISSIPPI 68.0
NORTHERN TEXAS 99.5
CENTRAL CALIFORNIA 1905.0
CENTRAL & SOU. ALABAMA 294.0
CENTRAL MISSISSIPPI 95.5
NORTH & SOUTH CAROLINA 967.3
NORTHERN ALABAMA 100.3
CENTRAL & SOU. ARKANSAS 505.7
TENNESSEE 1571.5
VIRGINIA 779.0
OZARK REGION 748.0
KENTUCKY 84.0
DELAWARE 1374.0
SOUTHERN ILLINOIS 268.2
MARYLAND 1569.3
KANSAS 104.8
CENTRAL COLORADO 41.0
OREGON & NORTHERN CALIFORNIA 277.8
WASHINGTON 327.0
SOUTHERN INDIANA 103.5
NEW JERSEY 248.7
IOWA 21.0
OHIO 15.9
HUDSON VALLEY, NEW YORK 122.0
WESTERN NEW YORK 54.5
MICHIGAN 321.7
CONNECTICUT 105.0
MINNESOTA & WISCONSIN 66.5
OSWEGO DISTRICT, NEW YORK 13.0
NORTHERN COLORADO 19.0
*Southern California season extends to December 1

Strawberry shipments, 1914.

[All numbers which are marked with an asterisk (*) are estimates, based upon the shipments for 1913 and figures furnished for the 1914 crop, previous to its being marketed. Figures for the actual shipments in 1914 from these stations have not been obtained.]

	Carloads.
Alabama:	
Castleberry section (Apr. 15 to June 1)—	
Castleberry	165.0
Atmore	28.0
Canoe	19.0
Sparta	5.0
Bolling	4.5
Evergreen	1.0
Total	222.5
York section (Apr. 15 to June 1)—	
Cuba	46.0
Livingston	4.5
York	1.0
Total	51.5
Cullman section (Apr. 15 to June 5)—	
Cullman	83.0
Hanceville	16.0
Vinemont	1.0
Madison	.3
Total	100.3
Thorsby section (Apr. 20 to June 1)—	
Thorsby	20.0
State total	394.3
Arkansas:	
Southwest section (Apr. 25 to June 1)—	
Horatio	15.0
Camden	6.0
Belton	4.0
McCaskill	*3.0
Eagle Mills	2.5
Wickes	1.3
Bearden	1.0
Prescott	*1.0
Total	33.8
Judsonia section (Apr. 25 to June 5)—	
Judsonia	252.0
Bald Knob	74.0
Morrilton	37.0
Searcy	36.0
McRae	21.3
Conway	9.3
Bradford	8.0
Pangburn	8.0
Russellville	8.0
Beebe	6.0
Austin	5.0
Plumerville	4.0
Leslie	2.0
Russell	1.3
Total	471.9
Ozark section (May 1 to June 5)—	
Johnson	35.0
Decatur	34.0
Alma	32.0

	Carloads.
Arkansas—Continued.	
Ozark section (May 1 to June 5)—Con.	
Springdale	32.0
Van Buren	32.0
Dyer	18.0
Farmington	15.0
Rudy	12.5
Mulberry	12.0
Sulphur Springs	10.0
Abbott	8.0
Mount Comfort	8.0
Fayetteville	7.0
Lilburn	7.0
Tonitown	7.0
Garfield	6.5
Highfill	6.0
Gentry	5.0
Gravette	4.0
Lowell	3.0
Steele	*3.0
Healing Springs	2.0
Mountainburg	2.0
Greenland	1.5
Lincoln	1.3
Cave Springs	1.0
Elm Springs	1.0
West Fork	1.0
Hiwassee	.5
Coal Hill	.3
Winslow	.3
Furry	.0
Rogers	.0
Stewart	.0
Total	307.9
State total	813.6
California:	
Los Angeles section (Mar. 1 to Dec. 1)—	
Puente	177.0
Gardena	119.0
Moneta	46.0
Irwindale	17.0
Azusa	14.0
Glendora	.5
Total	373.5
Sacramento section (Mar. 25 to Aug. 15)—	
Florin	249.0
Elk Grove	6.0
Total	255.0
Placer County section (Apr. 1 to June 1)—	
Newcastle	43.0
Bowman	12.0
Loomis	10.0
Sebastopol	9.0
Penryn	2.0
Total	76.0

	Carloads.
California—Continued.	
Fresno section (Apr. 1 to Aug. 15)—	
Fresno	42.0
Santa Clara-Santa Cruz section (Apr. 1 to Dec. 1)—	
Gilroy, Sargent, Vega	1,010.0
Watsonville	242.0
Alviso	173.0
Mountain View	19.0
Pajaro	17.0
Aromas	14.0
Niles	13.0
Palo Alto	*12.0
Salinas	7.0
Agnew	6.0
San Carlos	6.0
Capitola	4.0
Lawrence	4.0
Irvington	3.0
Menlo Park	2.0
Total	1,532.0
Siskiyou section (May 20 to July 15)—	
Pioneer	31.0
Sisson	2.5
Total	33.5
State total	2,312.0
Colorado (May 20 to Sept. 1):	
Steamboat Springs	19.0
Canon City	12.0
Montrose	12.0
Denver	5.0
Fruita	3.0
Florence	2.5
Longmont	2.0
Grand Junction	1.8
Delta	1.7
Loveland	1.0
State total	60.0
Connecticut (June 15 to July 1):	
Broadbents Siding	60.0
Hamden	24.0
Branford	21.0
State total	105.0
Delaware (May 15 to June 20):	
Selbyville	428.0
Bridgeville	325.5
Frankford	104.0
Millsboro	91.0
Seaford	69.0
Georgetown	56.0
Rehoboth	42.0
Cannon	39.0
Delmar	36.5
Laurel	28.0
Greenwood	22.0
Smyrna	22.0
Dagsboro	20.0
Wyoming	20.0
Lincoln	16.0
Felton	11.0
Hartley	10.0
Woodside	10.0

	Carloads.
Delaware (May 15 to June 20)—Contd.	
Viola	8.0
Cheswold	4.5
Harrington	4.0
Milford	2.5
Redden	2.0
Clayton	1.5
Hickman	1.0
Farmington	.5
State total	1,374.0
Florida:	
Plant City section (Dec. 1 to Apr. 1)—	
Plant City	88.0
Lakeland	51.5
Dover	6.5
Kathleen	5.5
Bowling Green	.5
Wauchula	.5
Total	152.5
Stark section (Feb. 10 to May 15)—	
Lawtey	178.0
Stark	177.0
Hampton	10.0
Maxville	6.0
Lake Butler	3.0
New River	2.0
Theressa	*2.0
Total	378.0
State total	530.5
Illinois (May 15 to June 20):	
Anna	100.0
Villa Ridge	75.0
Pulaski	36.0
Dongola	24.0
Makanda	17.0
Cobden	6.5
Wetaug	4.0
Ullin	3.0
Richview	2.0
Balcom	.7
State total	268.2
Indiana (May 25 to June 25):	
New Albany	60.0
Borden	30.0
Pekin	11.0
Westville	2.5
State total	103.5
Iowa (June 1 to June 20):	
Keokuk	10.0
Montrose	8.0
Cedar Rapids	3.0
State total	21.0
Kansas (May 20 to June 20):	
Wathena	85.0
Troy	10.0
Leavenworth	8.3
Holton	1.0
Troy Junction	.5
State total	104.8

	Carloads.
Kentucky (May 10 to June 10):	
Bowling Green	75.0
Middletown	6.0
Kings Mountain	2.0
Louisville	1.0
State total	84.0
Louisiana (Mar. 15 to May 20):	
Independence	412.0
Hammond	294.0
Ponchatoula	240.0
Tickfaw	105.0
Amite	84.0
Albany	66.0
Natalbany	32.0
Roseland	5.0
Corbin	2.0
Genesee	2.0
Brookview	*1.0
State total	1,243.0
Maryland (May 15 to June 30):	
Marion Station	286.0
Baltimore	201.0
Pittsville	200.0
Fruitland	143.0
Goldsboro	74.0
Berlin	58.0
Westover	57.0
Showell	55.5
Princess Anne	50.0
Hopewell	45.0
Crisfield	44.0
Federalsburg	44.0
Whaleysville	41.0
Eden	40.0
Ridgely	40.0
Willards	40.0
Mardela Springs	33.0
Greensboro	27.0
Walstons	24.5
Parsonsburg	18.0
Kingston	10.0
Hebron	9.0
Salisbury	8.0
Loretto	5.0
Snow Hill	5.0
East New Market	4.0
Millington	*2.0
Williamsburg	2.0
Downes	*1.0
Marydel	1.0
Secretary	*1.0
Preston	.3
State total	1,569.3
Michigan (June 1 to July 18):	
Benton Harbor-St. Joseph	225.0
Bridgman	52.0
Bangor	14.0
Sawyer	14.0
Ludington	8.0
Oshtemo	*3.0
Rochester	*2.5
Covert	*1.3
Lacota	*1.3
Paxton	*.3
Watervliet	.3

Michigan (June 1 to July 18)—Contd.	Carloads.
Fennville	.0
Sodus	.0
State total	321.7
Minnesota (June 20 to July 10):	
Long Lake	8.6
Maple Plain	5.0
Howard Lake	1.3
Deer Wood	.5
Cedar Lake	*.3
State total	15.7
Mississippi:	
Gulf Section (Mar. 20 to May 15)—	
Bay St. Louis	5.0
Southern Osyka Section (Apr. 1 to May 15)—	
Osyka	36.0
Sanford Section (Apr. 10 to May 15)	
Sanford	27.0
Lauderdale Section (Apr. 15 to June 1)—	
Russell	29.0
Central Durant Section (Apr. 20 to May 20)—	
Durant	37.0
Madison	18.0
Ridgeland	8.0
West	2.0
Pickens	1.0
Tougaloo	*.5
McAdams	.0
Sallis	.0
Total	66.5
State total	163.5
Missouri (May 15 to June 20):	
Monett	63.0
Anderson	48.0
Neosho	45.0
Sarcoxie	34.0
Logan	32.0
Pierce City	25.0
Republic	23.0
Goodman	20.0
Butterfield	19.0
Purdy	18.0
Seneca	13.0
Aroma	10.0
McElhaney	*10.0
Carthage	8.0
Larussell	*7.0
Verona	6.5
Belfast	6.5
Exeter	6.0
Mount Vernon	6.0
Pomona	6.0
Wheaton	6.0
Lutesville	5.0
Diamond	*4.0
Seligman	4.0
Billings	3.0
Lanagan	3.0
Noel	2.0
Chadwick	1.0
Glenallen	1.0
Granby	1.0
Koshkonong	1.0

Missouri (May 15 to June 20)—Contd.	Carloads.
Marionville	1.0
Stark City	1.0
Richey	.8
Tipton Ford	.5
Wentworth	.3
State total	440.1

New Jersey (May 25 to June 25):	
Port Norris	63.0
Landisville	58.0
Moorestown	35.0
Hammondton	25.0
Vineland	23.0
Cedarville	20.0
Newport	10.0
Egg Harbor City	8.0
Pomona	4.0
Fairton	1.2
Medford	.5
Risley	.5
Winslow	.5
State total	248.7

New York (June 1 to July 1):	
Highland	60.0
Angola	50.0
Milton	38.0
Roseton	21.0
Oswego	13.0
Forestville	4.5
Calverton	3.0
State total	189.5

North Carolina (Apr. 15 to June 1):	
Mount Tabor	152.0
Mount Olive	145.0
Chadbourn	133.0
Rose Hill	95.0
Teacheys	66 0
Clarendon	36.0
Vineland	31.0
Wallace	28.0
Rocky Point	20.0
Abbottsburg	18.0
Bladenboro	17.0
Burgaw	17.0
Faison	16.0
Willard	10.0
Cerro Gordo	9.0
Wards Cut	7.0
Ashton	6.0
Elrod	6.0
Currie	5.0
Montague	5.0
Watha	3.0
Magnolia	2.0
Sanford	2.0
St. Helena	2.0
Warsaw	2.0
Atkinson	1.5
Dudley	1.5
Bowdens	1.0
Calypso	1.0
Clinton	.5
Kittrell	.4
State total	838.9

Ohio (June 1 to June 25):	Carloads.
Waterville	*8.0
Middleport	*4.0
East Rochester	2.0
Rutland	1.0
Dexter	.6
New Carlisle	.3
State total	15.9

Oklahoma (May 10 to June 10):	
Sallisaw	5.0
Muldrow	2.5
State total	7.5

Oregon (May 25 to July 15):	
Hood River	118.0
Free Water	40.0
Milton	23.0
Springbrook	18.8
Troutdale	9.0
Rex	7.5
Salem	6.0
Forest Grove	4.0
Cove	3.0
Dillard	3.0
Lebanon	3.0
Ashland	2.0
Hillsboro	2.0
Newberg	2.0
Union	2.0
Roseburg	1.0
State total	244.3

South Carolina (Apr. 12 to May 25):	
Loris	79.0
Conway	24.0
Adrain	10.0
Sanford	6.0
Homewood	4.0
Allen	3.0
Clarks Hill	1.0
Myrtle Beach	1.0
Lake City	.2
Meriwether	.2
State total	128.4

Tennessee:	
Chattanooga section (May 1 to June 5)—	
Spring City	110.0
Dayton	109.0
Evensville	109.0
Bakewell	36.0
Knoxville	30.0
Chattanooga	24.0
Sale Creek	15.5
Soddy	12.0
East Chattanooga	8.0
Harriman	8.0
Rockwood	6.0
Roddy	5.0
Lancing	2.5
Athens	2.0
Hixson	2.0
Cleveland	1.0
Coulterville	1.0
Total	481.0

Tennessee—Continued.	Carloads.
Dyer-Sharon-Humboldt section (May 1 to June 5)—	
Humboldt	267.0
Sharon	83.0
Currie	72.0
Curve	71.5
Ripley	70.0
Gates	66.0
Dyer	64.0
Kenton	64.0
Medina	56.0
Jackson	52.0
Bradford	39.0
Gadsden	35.0
Halls	27.0
Trezevant	25.0
Bells	23.0
Greenfield	18.0
Rutherford	13.5
Milan	13.0
Dresden	*10.0
Nashville	6.0
Henderson	5.0
Henning	4.0
Trenton	4.0
Gibson	2.0
Fruitland	.5
Bartlett	.0
Total	1,090.5
State total	1,571.5
Texas:	
Alvin section (Mar. 1 to May 15)—	
Dickinson	53.0
Alvin	43.0
Deepwater	9.0
League City	7.0
La Porte	2.5
Webster	.6
Poteet	.5
Total	115.6
Artesian Belt section (Mar. 1 to May 15)—	
Carrizo Springs	11.0
Tyler section (Apr. 1 to May 10)—	
Winnsboro	32.0
Tyler	29.0
Lindale	15.0
Swan	12.0
Chandler	*4.0
Arp	2.3

Texas—Continued.	Carloads.
Tyler section (Apr. 1 to May 10)—Contd.	
Whitehouse	*2.0
Troup	1.5
Jefferson	1.0
Edgewood	.5
Cookville	.2
Total	99.5
State total	226.1
Utah (June 5 to July 1):	
Centerville	*1.0
Farmington	.4
State total	1.4
Virginia:	
Norfolk section (May 1 to June 1)	629.0
Albemarle section (May 1 to June 5)—	
Crozet	4.0
Eastern Shore section (May 5 to June 5)	146.0
State total	779.0
Washington (May 20 to July 15):	
Auburn	102.6
Kennewick	56.3
White Salmon	48.5
Sumner	43.8
Spokane	31.0
Puyallup	19.0
Seattle	6.0
Tacoma	5.0
Underwood	3.8
Kent	3.0
Mabton	3.0
Prosser	3.0
Montesano	1.0
Lynden	.5
Opportunity	.5
Sumas	.0
State total	327.0
Wisconsin (June 5 to July 15):	
Sparta	20.0
Bayfield	17.0
Sturgeon Bay	7.0
Sawyer	3.0
Millston	2.5
West Salem	*1.0
Green Bay	.3
State total	50.8
Grand total	14,553.2

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WM. A. TAYLOR, Chief

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SUGAR BEETS: PREVENTABLE LOSSES IN CULTURE.

By HARRY B. SHAW, *Assistant Pathologist, Cotton and Truck Disease and Sugar-plant Investigations.*

CONTENTS.

INTRODUCTION.

The cultivation of the sugar beet for the manufacture of sugar has been developed in Europe into one of the most important industries. This industry was transplanted thence into the United States, where the basis of labor costs and farm methods are quite different from those of Europe. Therefore, American beet growers must work out many problems in adjusting their cultural practices to their labor, soil, and climatic conditions.

It is of vital importance, if we are to compete successfully with other sugar-producing countries and secure the largest possible profit, that the cost of producing each ton of beets be reduced to a minimum.

Attention must be paid to details, in order to check the leaks responsible for low yields, for with sugar beets, as with most of our field crops, it is unfortunately true that the average yield per acre in the United States, despite its deep, rich soils, is lower than that of any European beet-growing country except Russia, as may be seen from Table I, which shows the yields for 1910 and 1911.

Doubtless climatic variations between one European country and another and between widely separated parts of the United States have a perceptible influence upon the yield, and it is extremely probable that the countries producing the heaviest yields are those in which the application of thorough cultural methods is the more general. It is also true of the United States, as compared with European countries, that the cost of labor is high and that land values are relatively low, one result of which is that much less labor to the acre is applied in this country than in Europe.

TABLE I.—*Acreage of sugar beets and production of sugar of seven of the principal beet-growing countries.*[1]

Country.	Sugar production.	Area of sugar beets sown.	Yield of sugar beets per acre.	Sugar obtained from beets.
	Tons.	*Acres.*	*Tons.*	*Per cent.*
Germany	2,854,812	1,169,755	14.84	16.31
Russia	2,324,486	1,614,780	8.93	16.12
Austria-Hungary	1,678,566	913,159	12.38	14.85
France	783,925	571,805	10.63	12.90
Belgium	312,196	150,176	14.53	14.31
Holland	239,073	122,638	12.96	15.04
United States	510,172	398,029	10.17	12.61

[1] Compiled from the corrected figures of the International Association for Gathering Sugar Statistics. See Amer. Sugar Indus., v. 14, 1912, no. 1, p. 24; no. 2, p. 21.

STRIKING DIFFERENCES IN LOCAL YIELD.

One of the most striking facts in our agriculture is the enormous variation in yield obtained by different farmers in the same district, and often by near neighbors applying identical methods under similar soil and climatic conditions. These differences can not be attributed entirely to variations in soil, in climate, or in the methods themselves; nor, in the case of sugar beets, can they be accounted for by variations in the quality of the seed, because beet seed is invariably furnished by each sugar factory from its common stock. In many districts the seed is sown by the sugar company.

True enough, there are variations in soil and in methods, but these are not sufficient to account for the great discrepancies in yield everywhere to be observed. For example, within a small area under similar soil conditions, with identical climatic conditions and employing like methods, one may find a farmer rejoicing as he hauls 20 tons of beets from each acre to the factory, while his neighbor is almost too discouraged to load his pitiful 7 or 8 tons an acre into his wagon.

Of equal significance is the fact that while the yields from two or more individual fields may differ greatly, yet a glance over these fields after the foliage has attained some size, or even soon after thinning, might fail to reveal any appreciable difference in the stand. However, a careful examination of such fields would show that in general the plants in some fields are more widely spaced than in others and that gaps, not apparent at a distance, occur more or less frequently in the rows. Beet growers fail to realize the significance of these apparently small deficiencies in the stand.

In the course of field observations on sugar beets covering a period of several years, the local variations in yield were seen to be so remarkable that special studies were begun in order to ascertain the actual conditions prevailing in fields belonging to a number of representative beet growers in old established beet districts in Utah. These studies were commenced in 1910 and continued through the seasons

of 1911 and 1912, all of which seasons were favorable in that no unusual conditions arose, such as outbreaks of disease or invasions of insect pests; in other words, they might be called normal seasons.

Care was taken to select plats on groups of farms having similar soil conditions and where identical methods were employed. Climatic factors within each group were identical, since each group was located within a very restricted territory. Notes were made on the condition and preparation of the soil, of the dates of sowing, and of the various operations throughout the season. The farmers whose plats were under observation were not informed of the nature of the studies, but were left to carry on their operations in the accustomed manner.

Primarily, then, this is an attempt to reveal the actual conditions of commercial beet fields as they may be found in any average season in well-established beet districts and to ascertain whether any correlation exists between these conditions and the respective yields.

VARIATION IN STAND.

At an early stage of these observations a variation in the number of plants to the acre was discovered in the fields mentioned. This was quite as remarkable as the variation in yield. Furthermore, it became apparent that in the course of the season the percentage of stand progressively decreased to a surprising extent. The periods during which further losses in stand occurred indicated very clearly the chief factors concerned.

THREE TYPES OF SOIL STUDIED.

To discover the conditions prevailing on farms located on the principal types of soil, plats were selected on farms possessing in turn the following types: (1) Deep, sandy loam, well manured and in excellent tilth, where the farmers are accustomed to truck crops; (2) very light sandy loam, generally well manured and in good tilth, where intensive culture is practiced to some extent; and (3) heavy black loam, moderately well manured and in fair tilth, where general field crops are prevalent and much of the work is done by contract.

OBSERVATIONS IN 1910.

During the season of 1910 observations were made only in fields of heavy black loam, and no counts of the germination and thinning stands were taken, the data presented being based upon the condition of the harvest stands, accompanied by general notes during the season. These data are presented in Table II.

The small percentage of the harvest stands is startling. The major portion of this loss was due to careless spacing and thinning. The work was done by contract labor, with practically no supervision.

TABLE II.—*Analysis of observations made on beet plats and their yields in 1910, 1911, and 1912.*

Plat and character of soil.	Number of rows.	Length of rows.	Area of plat.	Germination stand.	Thinning stand.	Harvest stand.	Yield of plat.	Number of beets in plat.	Number of beets per acre.[1]	Average weight per beet.	Yield per acre.	Sugar in beet.	Purity.	Loss before thinning.	Loss by thinning.	Loss between thinning and harvesting.	Total loss or deficiency.	Actual average spacing of beets.	Date harvested.	Notes.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Season of 1910:		Feet.	Acres.	P. ct.	P. ct.	P. ct.	Lbs.			Lbs.	Tons.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	In.		
Plat 1. Heavy black loam.	7	395½	0.1052	......	......	45.71	2,742	1,886	17,920	1.453	13.032	......	......	......	......	......	54.29	17.5	Oct. 20......	Plowed about 8 inches deep; contract labor; other conditions normal.
Plat 2. Heavy black loam.	7	395½	.1052	......	......	45.51	2,834	1,878	17,850	1.508	13.469	......	......	......	......	......	54.49	17.5	.....do......	
Plat 3. Heavy black loam.	10	273	.1043	......	......	39.58	2,417	1,619	15,520	1.492	11.586	......	......	......	......	......	60.42	20.5	.....do......	
Mean of 1910......	......	......	......	......	......	43.60	......	......	......	......	12.695	......	......	......	......	......	56.40	18.5	....	
Season of 1911:																				
Plat B. Sandy loam.	8	150⅔	.0460	(2)	81.15	76.83	2,809	1,386	30,120	2.026	30.532	......	......	......	18.85	4.32	23.17	10.4	Oct. 20 to 30.	See No. 1, Table III.
Plat A. Sandy loam.	8	75⅓	.0230	(3)	86.68	64.41	616	581	25,250	1.06	13.391	......	......	......	13.32	22.27	35.59	12.4	.....do......	See No. 9, Table III.
Plat D. Sandy loam.	8	150⅔	.0460	(4)	58.93	49.66	2,463	896	19,470	2.748	26.773	......	......	......	41.07	9.27	50.34	16.3	.....do......	See No. 3, Table III.
Plat C. Light sandy loam.	8	150⅔	.0460	(5)	87.80	......	......	......	......	......	......	......	......	......	12.20	......	......	......	....	Data after thinning not available.
Plat E. Heavy black loam.	8	315	.0964	(6)	60.64	52.30	2,988	1,976	20,500	1.512	15.497	......	......	......	39.36	8.338	47.70	15.1	Oct. 20 to 30.	See No. 15, Table III.
Plat F. Heavy black loam.	8	352	.1077	(7)	60.97	48.12	2,655	2,032	18,870	1.306	12.325	......	......	......	39.03	12.85	51.88	16.6	.....do......	See No. 16, Table III.
Plat G. Heavy black loam.	18	210	.1446	(8)	......	45.62	5,005	2,586	17,880	1.935	17.306	......	......	......	......	......	54.38	17.5	.....do......	See No. 18, Table III.
Mean of plats:																				
A to D..........	......	......	......	......	78.64	63.63	......	......	......	......	23.565	......	......	......	21.36	11.95	36.36	13.03	....	
E to G..........	......	......	......	......	60.80	48.68	......	......	......	......	15.042	......	......	......	39.19	10.59	51.32	16.40	....	
All in 1911......	......	......	......	......	72.69	56.155	......	......	......	......	19.304	......	......	......	27.30	11.40	43.845	14.7	....	

Season of 1912, group 1:																				
Plat 1. Light sandy loam.	4	330	.0505	87.93	54.36	46.99	2,780	930	18,420	2.990	27.524	17.30	90.00	12.07	33.57	7.37	53.01	17.02	Oct. 24......	See No. 4, Table III.
Plat 2. Light sandy loam.	4	330	.0505	64.00	43.88	37.19	1,960	736	14,570	2.663	19.406	17.30	90.00	36.00	20.12	6.69	62.81	21.50	.....do......	See No. 6, Table III.
Plat 3. Light sandy loam.	4	414	.0633	91.15	58.25	50.54	3,000	1,254	19,810	2.392	23.696	17.80	90.30	8.85	32.90	7.71	49.46	15.80	.....do......	See No. 2, Table III.
Plat 4. Light sandy loam.	4	414	.0633	65.74	45.23	38.57	2,460	957	15,120	2.570	19.431	17.80	90.30	34.26	20.51	6.66	61.43	20.70	.....do......	See No. 5, Table III.
Mean, group 1......	....	......	......	77.20	50.43	43.32	......	......	......	......	22.514	17.55	90.15	22.79	26.77	7.11	56.68	18.75	....	
Season of 1912, group 2:																				
Plat 5. Very light sandy loam.	4	585	.0895	94.67	79.65	77.11	4,230	2,705	30,220	1.564	23.631	19.60	......	5.33	15.12	2.54	22.99	10.4	Oct. 27......	Soil not so deeply plowed as in plats 1, 2, 3, and 4, but more sandy; owner's labor and supervision.
Plat 6. Sandy loam..	4	268	.0410	93.16	73.15	68.20	1,710	1,096	26,730	1.560	20.853	18.50	......	6.84	20.01	4.95	31.80	11.7	Oct. 22......	
Plat 7. Loam........	4	515	.0788	72.64	63.75	59.82	2,690	1,848	23,450	1.455	17.068	......	......	27.36	8.89	3.93	40.18	13.5	Nov. 6......	See No. 11, Table III.
Plat 8. Very light sandy loam.	6	306	.0702	87.53	65.30	60.26	2,420	1,658	23,600	1.459	17.236	17.80	......	12.47	22.23	5.04	39.74	13.3	Sept. 28.....	See No. 10, Table III.
Plat 9. Very light sandy loam.	4	390	.0596	78.33	60.25	52.48	1,660	1,226	20,570	1.354	13.926	18.00	......	21.67	18.08	7.77	47.52	15.2	Sept. 20.....	Much of the work done by boys, with little supervision.
Mean, group 2......	....	......	......	85.26	68.42	63.57	......	......	......	......	18.543	18.47	......	14.73	16.86	4.84	36.44	12.8	....	
Season of 1912, group 3:																				
Plat 10. Heavy black loam.	10	320	.1224	80.05	68.35	63.13	2,340	3,029	24,760	0.772	9.558	15.20	89.60	19.95	11.70	5.22	36.87	12.6	Nov. 28.....	See No. 13, Table III.
Plat 11. Heavy black loam.	8	277	.0847	89.04	67.20	60.12	2,585	1,996	23,570	1.295	15.253	18.90	89.90	10.96	21.84	7.08	39.88	13.3	.....do......	Owner's labor; conditions about normal.
Plat 12. Heavy black loam.	8	309	.0945	76.13	49.29	37.98	2,227	1,407	14,890	1.580	11.733	18.00	88.60	23.87	26.84	11.31	62.02	21.1	Oct. 20......	Contract labor; conditions about normal.
Plat 13. Heavy black loam.	8	332	.1016	68.50	42.00	29.55	2,096	1,177	11,580	1.780	10.314	19.95	90.85	31.50	26.50	12.45	70.45	27.4	Oct. 17......	See No. 22, Table III.
Mean, group 3......	....	......	......	78.43	56.71	47.69	......	......	......	......	11.714	18.01	89.74	21.57	21.72	9.01	52.30	18.6	....	
Mean of all, 1912....	....	......	......	80.68	59.28	52.46	......	......	......	......	17.679	18.01	89.94	19.31	21.41	6.82	47.55	16.4	....	

[1] Correct to 25 beets or less per acre.
[2] Good; gaps due to faulty dr ill.
[3] Irregular, spotty.
[4] Fair, irregular.
[5] Good, but rather spotty.
[6] Only fair.
[7] Rather poor.
[8] Fairly good.

OBSERVATIONS IN 1911.

During the season of 1911 general notes were made of the germination stands without actual measurements or counts. Seven fields were kept under observation, including soil types 2 and 3, namely, light sandy loam and heavy black loam. These data also are presented in Table II.

OBSERVATIONS IN 1912.

During 1912 the studies were extended to include all three types of soil. Careful notes were made of the germination stand prior to thinning. The selected rows extended entirely across the field in each instance. The data obtained are shown in Table II.

ANALYSIS OF OBSERVATIONS.

The analysis of observations for the season of 1910, as presented in Table II, shows a complete correlation between yield and percentage of stand. The small percentage of the ultimate stand is surprising, the mean being only 43.6 per cent, and, although the average weight of the beets is 1.453, 1.508, and 1.492 pounds, respectively, the excess over 1 pound did not nearly compensate for the large area occupied by each plant. This deficiency of stand was caused largely by careless spacing and thinning. All the work was done by contract labor with practically no supervision. The plats were in adjacent fields, where the general conditions and cultural operations were almost identical.

The harvest stands for 1911, though appreciably better than those shown by the plats of 1910, exhibit a mean of only 56.155 per cent (Table II). The correlation between stand and yield is rather obscured by the special factors which developed during the season on several plats. However, these factors throw additional sidelights on the studies, since their influence on yield is very apparent. For example, on plat A the cultural operations were left almost entirely to young boys, without oversight. The thinning was very carelessly done, 6.89 per cent of the plants being left in pairs, which, for practical purposes, means their entire loss. Weeds were allowed to choke the beets for a great part of the season. On the other hand, the owner of plat B is well known to be a fine truck grower, who does all the work with the assistance of his own family. The soil, through years of intensive farming, is very deep and mellow.

Plat D is located on much lighter soil than plat B, but with a stand of considerably lower percentage it yielded almost as much for each acre. This, in connection with the record of plats 1, 2, 3, and 4, of 1912, brings out the fact, which is contrary to the prevailing notion, that beets will yield more heavily in deep light sandy soils if they are well manured than in the somewhat heavy loams that have been regarded as more typical beet soils.

Plat E shows a fairly normal correlation between stand and yield, while plat F decreases on account of late and careless thinning, no less than 9.82 per cent of pairs of plants being found.

Plat G shows a greater yield than plat E, because its soil was very well prepared and manured and the cultural work done by Japanese who were working for themselves.

Referring to the analysis of observations for the season of 1912, as presented in Table II, the plats in group 1 were operated under almost experimental conditions. The seed was sown under the direction of the writer. Two pairs of plats were studied, one pair in each of two contiguous fields possessing very uniform soil. One farmer worked plats 1 and 2 while another farmer worked plats 3 and 4. The rows extended entirely across each field. The two farmers carried on or supervised all the cultural operations. The only appreciable difference in the handling of the plats was that the seed was sown slightly deeper in one plat of each pair than in the other. This resulted in more damping-off in the deeper sown plats, thus producing therein rather poorer stands. In this group the correlation between yield and stand is complete. From this group and plat D of 1911 it would appear that the optimum area per plant is considerably greater in deep, light, well-manured sandy soils than in loams and heavy loams. In group 2 a perfect correlation is shown between yield and stand. At the same time, the effect of inexperience and lack of supervision is evident in plat 9. In group 3 the correlation between stand and yield actually is accentuated by the exception shown in plat 10. This discrepancy is entirely accounted for by the adverse conditions to which this plat was subjected.

CORRELATION OF STAND AND YIELD.

In Table III all the plats for the three years are arranged according to the percentage of the harvest stand, beginning with the highest. They are divided into three groups, representing three soil types. In this table the percentage of the harvest stand is placed side by side with the yield of each plat. This reveals a striking correlation between the percentage of stand and the yield. The apparent exceptions are accounted for by the special conditions described under the heading "Notes" in Tables II and III. Upon allowing for the adverse or especially favorable conditions mentioned, it may be said that the correlation is complete.

In Table III the means of the yields of groups 2 and 3 exhibit a ratio almost exactly equal to the relation of their respective stands. Based on the figures given, the mean yield of group 3 would be 17.72 if the stand were the same as in group 2.

TABLE III.—*Comparison of the harvest stands and the yields of sugar beets for the seasons of 1910, 1911, and 1912.*

Reference No.	Plat and season.	Notes.	Harvest stand.	Yield per acre.
	Group 1.—Deep sandy loam:		*Per cent.*	*Tons.*
1	Plat B (1911)	Deep, well-manured soil; crops rotated; owned and worked by experienced truck farmer.	76.83	30.532
2	Plat 3 (1912)	Rather deeply worked, well-manured soil, in good tilth; crops rotated; Nos. 2 and 5 in same field—very uniform, contiguous to the field in which Nos. 4 and 6 are located.	50.54	23.696
3	Plat D (1911)	Deeply worked soil, in fine tilth; crops rotated; owner's labor and supervision.	49.66	26.773
4	Plat 1 (1912)	Very deeply worked, well-manured soil; crops rotated; blocking and thinning done by contract, all other labor done by owner; Nos. 4 and 6 in same field—very uniform.	46.99	27.524
5	Plat 4 (1912)	Same as No. 2, except that seed was sown rather deeper, resulting in more damping-off in the spring.	38.57	19.431
6	Plat 2 (1912)	Same as No. 4, except that seed was sown rather deeper, resulting in more damping-off in the spring.	37.19	19.406
	Group 2.—Very light sandy loam:			
7	Plat 5 (1912)	Soil not plowed so deeply as in Nos. 2, 4, 5, and 6, but more sandy; owner's labor and supervision.	77.11	23.631
8	Plat 6 (1912)	do	68.20	20.853
9	Plat A (1911)	Very badly thinned, spacing irregular, 6.89 per cent of the plants in pairs; choked with weeds; labor mostly done by young boys without supervision.	64.41	13.391
10	Plat 8 (1912)	Plants tardy in the spring, owing to late sowing; soil in good tilth; owner's labor; good farmer.	60.26	17.236
11	Plat 7 (1912)	Second sowing; plants rather tardy in the spring; soil in good tilth; owner's labor; good farmer.	59.82	17.068
12	Plat 9 (1912)	Much of the work done by boys, with little supervision.	52.48	13.926
	Group 3.—Heavy black loam:			
13	Plat 10 (1912)	Ground not plowed, only disked and harrowed; severe hailstorm in mid-August defoliated the beets.	63.13	9.558
14	Plat 11 (1912)	Owner's labor; conditions about normal	60.12	15.253
15	Plat E (1911)	Land in good tilth; too much contract labor; 2.56 per cent of the plants in pairs.	52.30	15.497
16	Plat F (1911)	Sowed and thinned rather late, thinning badly done; 9.82 per cent of plants in pairs; contract labor.	48.12	12.325
17	Plat 1 (1910)	Contract labor; soil plowed about 8 inches deep; other conditions normal.	45.71	13.032
18	Plat G (1911)	Soil in good tilth, heavily manured, deeply plowed; Japanese working for themselves.	45.62	17.306
19	Plat 2 (1910)	Like No. 17	45.51	13.469
20	Plat 3 (1910)	do	39.58	11.586
21	Plat 12 (1912)	Contract labor; conditions about normal	37.98	11.733
22	Plat 13 (1912)	Contract labor; 2.03 per cent loss by cutting an irrigation ditch through the plat; other conditions normal.	29.55	10.314
	Mean of group 1		49.96	24.562
	Mean of group 2		63.71	17.684
	Mean of group 3		46.76	13.007
	Mean of all plats		52.26	17.432

SOURCES OF LOSS IN STAND.

Sources of losses of great magnitude in the stand are brought to light by an examination of the data presented in Table II. The factors directly causing a decrease in the number of plants to the acre were found to be susceptible of arrangement into three groups,

namely: (1) Those occurring in the germination stand prior to thinning; (2) careless and improper thinning and blocking; and (3) those incidental to cultural operations between thinning and harvest.[1]

SOURCES OF LOSS IN THE GERMINATION STAND.

The sources of loss found between the time of sowing and the dual operation of spacing and thinning are (1) poor preparation of the seed bed; (2) imperfect operation of seed drills; (3) late frosts; (4) the damping-off disease; (5) the blowing of light, sandy soils; (6) flea beetles; and (7) cutworms or wireworms.

LOSSES IN STAND FROM THINNING.

Improper thinning was found to be the greatest single source of loss in stand, the more serious because nearly imperceptible and unsuspected. This loss is caused by the double operation of blocking and thinning. It is one of the most costly operations in the cultivation of sugar beets and, strange to say, the one most frequently intrusted to hired labor or contract work. Worse still, it is seldom efficiently supervised. Invariably the space left between the plants is greater than the farmer imagines or intends. When the plants have attained a moderate size, it is almost impossible to distinguish, without counting, between stands of 50, 60, or 80 per cent.

LOSSES IN THE HARVEST STAND.

The difference in the percentage of stand between that shown immediately after thinning and that existing at harvest time is to be attributed to inefficiency in the cultural operations during the intervening period. Some of these losses are caused by the eradication of plants with the hand hoe and their destruction by the hoofs of horses or by implements, especially when turning at the ends of rows, and by poor guidance of the cultivator, whereby it swerves and cuts out the plants along the rows. (In this way from one to four rows may be damaged at each round, according to the type of cultivator employed.) The flooding of low areas and the drying out of high ones, as well as cutting through rows to distribute water in poorly graded fields, are additional sources of loss. (See Table II.)

It soon became apparent that the observations could most profitably be confined to a determination of the nature and extent of losses in stand and their causes. From these data it appeared possible to discover whether correlations exist between such losses and the yield of the respective plats.

To ascertain the percentage of the stands throughout the season, measurements were made of the actual distance between all the plants in every row under observation, instead of obtaining merely the aver-

[1] Germination stand is the stand of beets resulting from the germination of the seed up to the time of thinning. Thinning stand is the stand or number of plants left after blocking and thinning. Harvest stand is the number of beets to the acre at harvest time.

age distance by counting the plants in each row and dividing the length of the rows by the number of plants. This was accomplished with the simple contrivance shown in figure 1.

THE SIGNIFICANCE OF POOR STANDS.

Having shown that progressive reductions in the percentage of stand occur throughout the entire season, and having indicated the factors chiefly concerned in this destruction of plants, an inquiry may be made as to the significance of these reduced percentages. Does the eradication of these beets from time to time during the season affect the ultimate yield, or does it happen that the remaining beets, being more widely spaced, so increase in size on account of the augmented area allowed to each plant as to compensate for the diminished number to the acre?

FIG. 1.—Graduated wooden rod used in measuring the gaps in a stand of sugar beets.

It is frankly conceded that evidence on this question might be inconclusive if based alone on observations of plats or fields on ordinary farms—that is, farms among which greater or less diversity of conditions exist, however much care may have been exercised in their selection; where the application of even identical methods will vary to some degree; and where there are other factors of variation known to everyone who has carried on such experiments. Fortunately many experiments have already been conducted under test conditions, both in Europe and in the United States, which conclusively demonstrate that with such crops as cotton, corn, mangel-wurzels, potatoes, turnips, carrots, lettuce, sugar beets, and other spaced crops an optimum area for each plant may be discovered. Only a few of these are cited.[1] To

[1] Holden, P. G., and Hopkins, C. G. The sugar beet in Illinois. Ill. Agr. Exp. Sta. Bul. 49, 52 p. illus., 1898.
Knauer, Ferdinand. Der Rübenbau . . . Aufl. 9, neubearb von Max Hollrung, p. 64–65. Berlin, 1906.
Nicholson, H. H., and Lyon, T. L. Experiments in the culture of the sugar beet in Nebraska. Nebr. Agr. Exp. Sta. Bul. 60, 34 p., 6 fig., 1899.
Shaw, G. W. Culture of the sugar beet. Cal. Agr. Exp. Sta. Circ. 13, 21 p., 3 fig., 1905.

reduce or to increase that area beyond certain limits results in a lessened yield per acre. Each crop requires its own special area per plant to yield the best results, but that area must be modified to some extent in different soils, with the available water supply and with climatic variations.

The cited experiments and practical experience alike show that the sugar beet requires, not only for the highest tonnage but also for the greatest yield of sugar per acre, an area of 144 to 160 square inches per plant, the optimum area varying somewhat with the character of the soil, fertilizers, and climate. In practice, the rows should be spaced not less than 18 or 20 inches apart, to facilitate cultural operations with horse implements. Commonly a distance of 20 inches has been adopted in the United States. This, then, is really a closed question. The spacing may be arranged by adjustment of the seed drill. The matter of importance is the spacing between the plants in the rows.

In most localities and in good beet soils a distance of 8 inches between plants is advised. Each beet would thus have 160 square inches, which, in round numbers, would give 39,200 plants per acre. This might be taken to represent a perfect stand and is the one employed in these tables as the standard for comparison. With beets averaging the moderate weight of 1 pound, such a stand would yield no less than 19.6 tons to the acre. In most of the beet districts of the United States the average weight of beets considerably exceeds this; it does so in all but one of the plats under observation. (See Table II, column 11.) We have seen that the average acre yield in this country during the season of 1910–11 was only 10.17 tons and that of Utah 11.42 tons, as compared with an average yield of 14.84 tons to the acre in Germany.

Since these facts have been experimentally established under test conditions, the data presented in Tables II and III acquire a real significance. Granting the impossibility of obtaining absolutely uniform conditions among the plats, even of each group, it would be unreasonable and illogical to repudiate the strong correlations found each season and to call them mere coincidences. One must acknowledge them to be examples of cause and effect. In short, it is held that the losses in stand indicated in these tables correspond more or less closely to the diminished yields.

As before stated, the apparent exceptions are accounted for by the specific adverse or especially favorable conditions mentioned in relation to them. The evidence of a relationship between the percentage of stand and the percentage of yield is strengthened to a degree almost equaling that obtained under strict experimental conditions by the fact that the data from two pairs of plats are presented, one pair being in each of two very uniform contiguous fields

where all the cultural operations were identical and carried on in each field by the same person. These are plats 1 and 2 and plats 3 and 4 of group 1, 1912. (See Table II.) In these two pairs of plats the correlation is perfect.

From these data, then, grave losses have been revealed in the percentage of stand of sugar beets. It has been demonstrated that a close relation exists between stand and yield; therefore it is apparent that such considerable losses in stand as have been indicated represent losses in tonnage. If data were collected from the fields of less experienced beet growers, still greater discrepancies would be revealed, which would correspond somewhat closely to their discouraging yields. Most of these losses are avoidable.

LOSSES ON A CASH BASIS.

The discrepancies among the yields of the fields under consideration will appear still more striking if translated into terms of dollars and cents. It is known that year after year some beet growers in the older districts (for example, those represented in groups 1 and 2, Table II) obtain no less than 30 tons of beets per acre, while in the district represented by group 3 (Table II) a yield of 25 tons an acre is not uncommon. Large yields are obtained annually by the most skillful beet growers in other States. It is acknowledged that yields such as those just mentioned are exceptional and are won only after the soil has been worked into splendid tilth by very deep plowing, ample manuring, and intensive culture. Perhaps such a standard might be open to the criticism that like results would be impracticable in general. For the purposes of comparison, then, the best plat in each group will be used. (See Table IV.)

Emphasis is placed on the fact that the yields mentioned in connection with the fields under consideration are not unusual, but are obtained by the same growers year after year with but slight fluctuation. Should it be contended that the soil in these fields is richer, deeper, or more fertile than that of other fields in the vicinity, where much smaller yields are obtained, it can be said of them that they are so chiefly because the owners or cultivators of those fields have brought them up to their present condition through better farming practices and not because the soil itself was markedly superior at the outset.

In regard to the sugar content of the beets, it can be said that the percentages quoted are those obtained from composite factory samples taken at random at the time of the delivery of the beets and determined by the chemist of the sugar factory. The season of 1912, when these tests were made, was not an exceptional one. It is undoubtedly true that weather conditions, especially in the latter part of the season, influence perceptibly the percentage of

sugar in the beet. However, it is also true in general that the beets of those growers who are skillful enough to obtain the best yields also show a relatively high percentage of sucrose. In some States the average percentage of sugar is annually lower than in others, probably on account of climatic differences. For that reason the standard set in this paper might have to be lowered somewhat to meet local conditions. In such places the standard obtained from the best beet growers in any specified locality could be substituted as a basis for calculating the deficiencies among the less successful beet growers.

There are two systems of payment in vogue, namely, the flat rate and the sliding scale. The flat rate adopted in this paper is below the average for the whole country, namely, $5 a ton for all beets containing more than the factory minimum of sucrose. The average price during 1913–14 was nearer $6 a ton.

TABLE IV.—*Comparison of the yields and cash receipts from various plats of sugar beets, for 1910, 1911, and 1912.*

Group and plat.	Year.	Actual yield.	Sugar in beet.	Actual returns.		Deficiency, on basis of yield of best plat.[1]	
				Flat rate.	Sliding scale.	Flat.	Sliding.
1	2	3	4	5	6	7	8
		Tons.	*Per cent.*				
Group 1:							
Plat B	1911	30.532	....	$152.66	....	....	....
Plat 3	1912	23.696	17.80	118.48	$131.27	$34.18	....
Plat D	1911	26.773	....	133.86	....	18.80	....
Plat 1	1912	27.524	17.30	137.62	148.35	15.04	....
Plat 4	1912	19.431	17.80	97.15	107.64	55.51	
Plat 2	1912	19.406	17.30	97.03	104.62	55.63	....
Mean	....	24.560	17.55	122.80	122.97	35.83	....
Group 2:							
Plat 5	1912	23.631	19.60	118.15	143.67	....	....
Plat 6	1912	20.853	18.50	104.26	119.90	13.89	23.77
Plat A	1911	13.391	....	66.95	....	51.20	....
Plat 8	1912	17.236	17.80	86.18	95.48	31.97	48.19
Plat 7	1912	17.068	....	85.34	....	32.81	....
Plat 9	1912	13.926	18.00	69.63	77.98	48.52	65.69
Mean	....	17.684	18.475	88.42	109.26	35.68	45.88
Group 3:							
Plat 10	1912	9.558	....	47.79	....	38.74	....
Plat 11	1912	15.253	18.90	76.26	89.53	10.27	....
Plat E	1911	15.497	....	77.48	....	9.05	....
Plat F	1911	13.325	....	66.62	....	19.91	....
Plat 1	1910	13.032	....	65.16	....	21.37	....
Plat G	1911	17.306	....	86.53	....	0	....
Plat 2	1910	13.469	....	67.34	....	19.19	....
Plat 3	1910	11.586	....	57.93	....	28.60	....
Plat 12	1912	11.733	18.00	58.66	65.70	27.87	....
Plat 13	1912	10.314	19.95	51.57	63.74	34.96	....
Mean	....	13.007	18.95	65.53	72.99	21.00	....
Mean of all plats	....	17.433	18.27	87.39	104.35	28.38	....

[1] In groups 1 and 3 the percentage of sucrose in the beets from the best plats is not known; therefore, the computations of receipts under the sliding scale can not be given for those groups.

For the sliding scale $5 a ton for beets containing 16 per cent of sucrose, with 30 cents a ton additional for every increment of 1 per cent in sugar content and a deduction of 25 cents a ton for every 1 per cent less than 16 per cent (fractional percentages in proportion), is taken to represent about the average rate.

A consideration of columns 5, 6, and 7 of Table IV will reveal the surprising magnitude of the discrepancies as compared with the yields of the best growers. In some cases this discrepancy is greater per acre than the actual cost of producing the crop, which averages about $42.50 an acre exclusive of manure, rent, or interest on the capital invested. The additional cost of manure would be about $15 to $20 an acre, but as this should preferably be applied to a preceding crop instead of directly to the beets this charge would be shared between two crops.

HOW TO OBTAIN BETTER STANDS.

Grave sources of loss have been revealed. They occur not among poor farmers alone, as might have been expected, but among those considered to be good. How great these losses are among the less successful farmers may be surmised after a moment's consideration. The average yield per acre of sugar beets in the United States for the season of 1910–11 was only 10.17 tons; the average for the State of Utah where these observations were made during the same period was 11.42 tons to the acre, while that among the better farmers as taken from these plats was 17.68 tons. Year after year the best beet growers obtain from 20 to 25 tons an acre. (Pl. I.) Therefore a large army of beet growers must obtain an average yield of much less than 10 tons an acre. Either their land is unsuited to profitable beet culture or their methods are bad or are very inefficiently carried out. In any case the real nature of the trouble should be ascertained. If the land is not adapted to beet culture, it would seem better to abandon that crop for a more profitable one; if their methods are at fault, the growers should be instructed by the factory field men.

To analyze data of this character and to indicate the causes of deficiency in stands of sugar beets, with the accompanying losses, are almost tantamount to pointing the way to an avoidance of such losses

GERMINATION LOSSES.

The average loss of stand caused by imperfect germination was 19.31 per cent (Table II, column 5), which was due largely to the poor preparation of the seed bed. In the first place, it was noted that fall plowing is seldom practiced and that it is rarely deep enough. One serious result of shallow plowing, early apparent in beet culture, is that weed seeds remain so near the surface that they are enabled

to germinate and sprout before the beet seedlings appear above ground, greatly retarding and stunting the latter. (Pl. II.)[1]

Too frequently manuring is delayed until spring, when, in conjunction with faulty preparation of the ground, pockets of half-rotted manure are left in the soil. These cause the taproots of seedling beets coming in contact with them to become sprangling and ill-shaped. It is believed to be the best practice to apply manure to a preceding crop instead of directly to beets.

In irrigated districts much loss is occasioned by the imperfect grading and leveling of the surface of the field; thus, low spots remain in some places and high ones in others. The low areas are

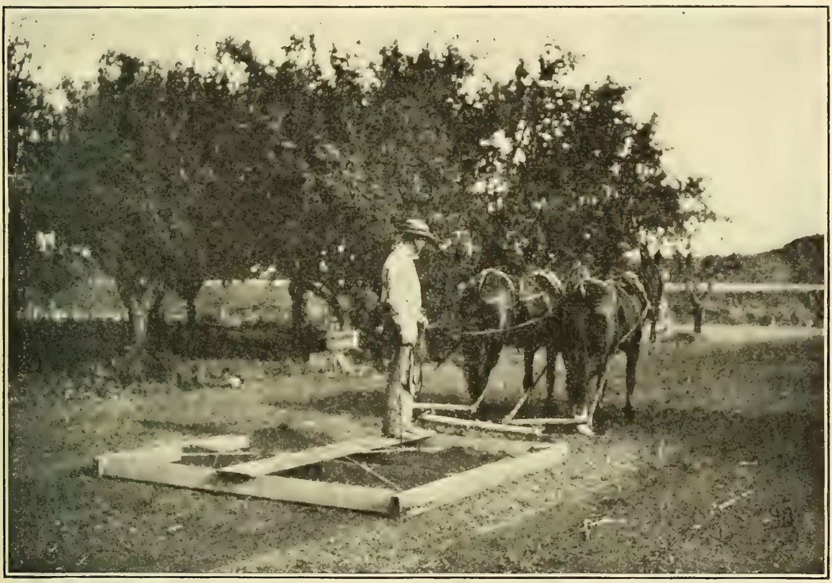


FIG. 2.—A homemade float used in leveling a beet field preparatory to sowing the seed.

flooded with every irrigation (Pl. III), while the elevated places, if extensive, suffer drought or render much extra work necessary to get the water over them. In either case, many plants are killed (fig. 3).

It is also apparent that losses in the stand occur on account of lack of responsiveness of the seed drills to irregularities in the surface of the field, resulting in the scattering of seed on the surface of the ground when individual drills pass over depressed areas. Little or none of the uncovered seed germinates; if the seed were slightly covered it might lie there in the dry surface soil until a shower caused

[1] The subsequent operations of disking, harrowing, and floating the fields (fig. 2) are not sufficiently thorough, leaving the seed bed too rough and cloddy and resulting in a reduced percentage of germination of the beet seed.

it to germinate later. Such belated plants add little to the tonnage. (Pl. IV.)

The damping-off disease exacts its toll every season; it may be so severe as to more than decimate the stand (Pl. V). It is occasioned partly by fungi borne on the seed balls, and partly by fungi present in the soil. This disease seems to be severe when the spring weather is unfavorable for the rapid and vigorous germination and growth of the beets.

An incrustation of the soil after rains sometimes prevents the young seedlings from breaking through, especially in heavy loams. These

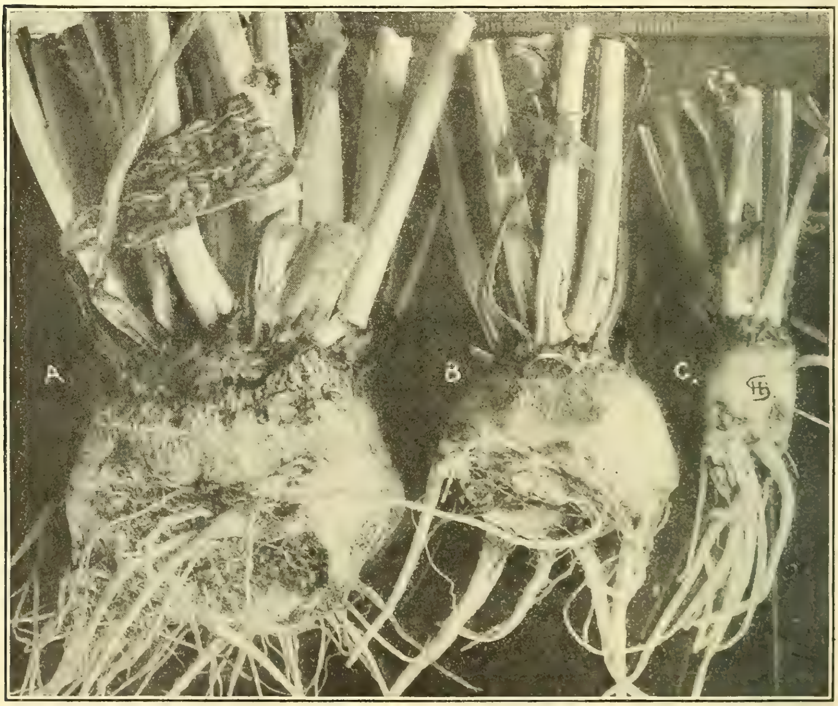


FIG. 3.—Three sugar beets, showing the effect of standing water or a wet subsoil upon the roots.

crusts may with advantage be broken with a corrugated roller. (Pl. VI.)

Wireworms and flea beetles are very troublesome and destructive in some localities (fig. 4). In this connection it would be of benefit to keep down weeds along fences, ditches, and roadsides. (Pl. VII.)

It is entirely practicable to increase the percentage of the germination stand to an extent that would amply repay the cost of the additional labor required. Deeper plowing should be more generally practiced. The extra disking and harrowing would require only a few hours more labor per acre. In irrigated regions the extra labor

A GOOD STAND OF SUGAR BEETS, WHICH WILL YIELD ABOUT 20 TONS TO THE ACRE, FROM A PRACTICALLY PERFECT GERMINATION STAND.

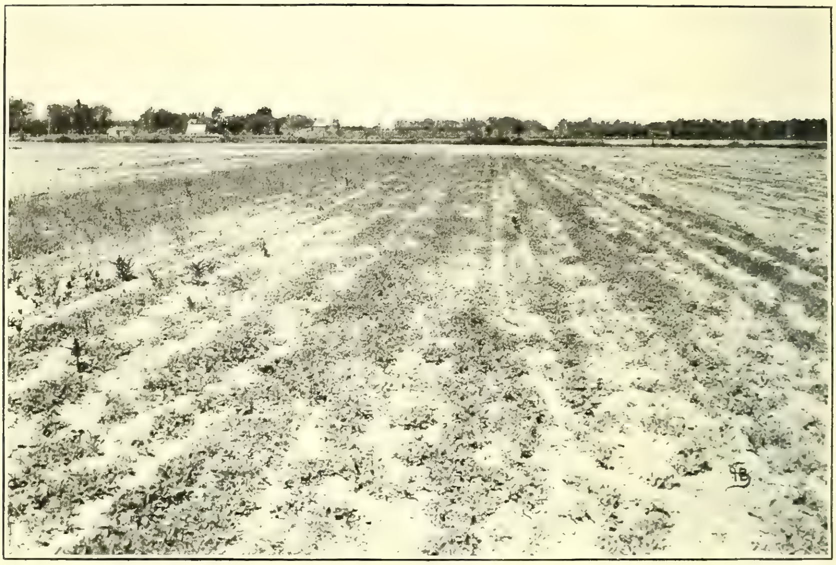


FIG. 1.—A SHALLOW-PLOWED BEET FIELD.

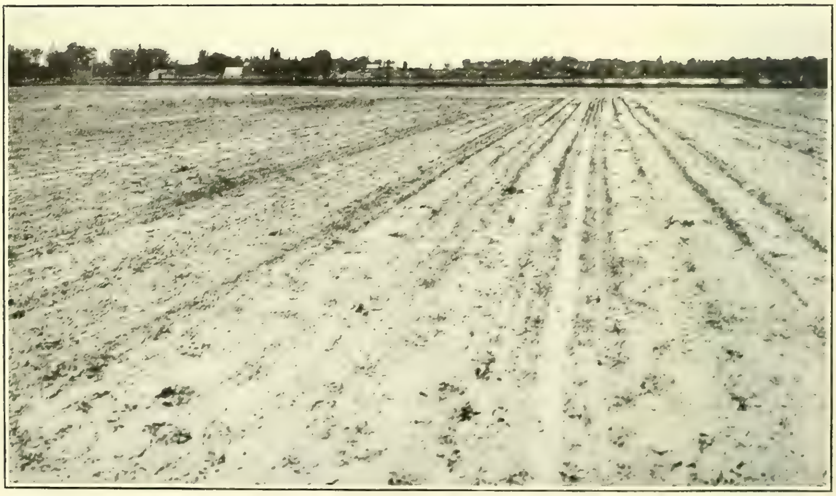
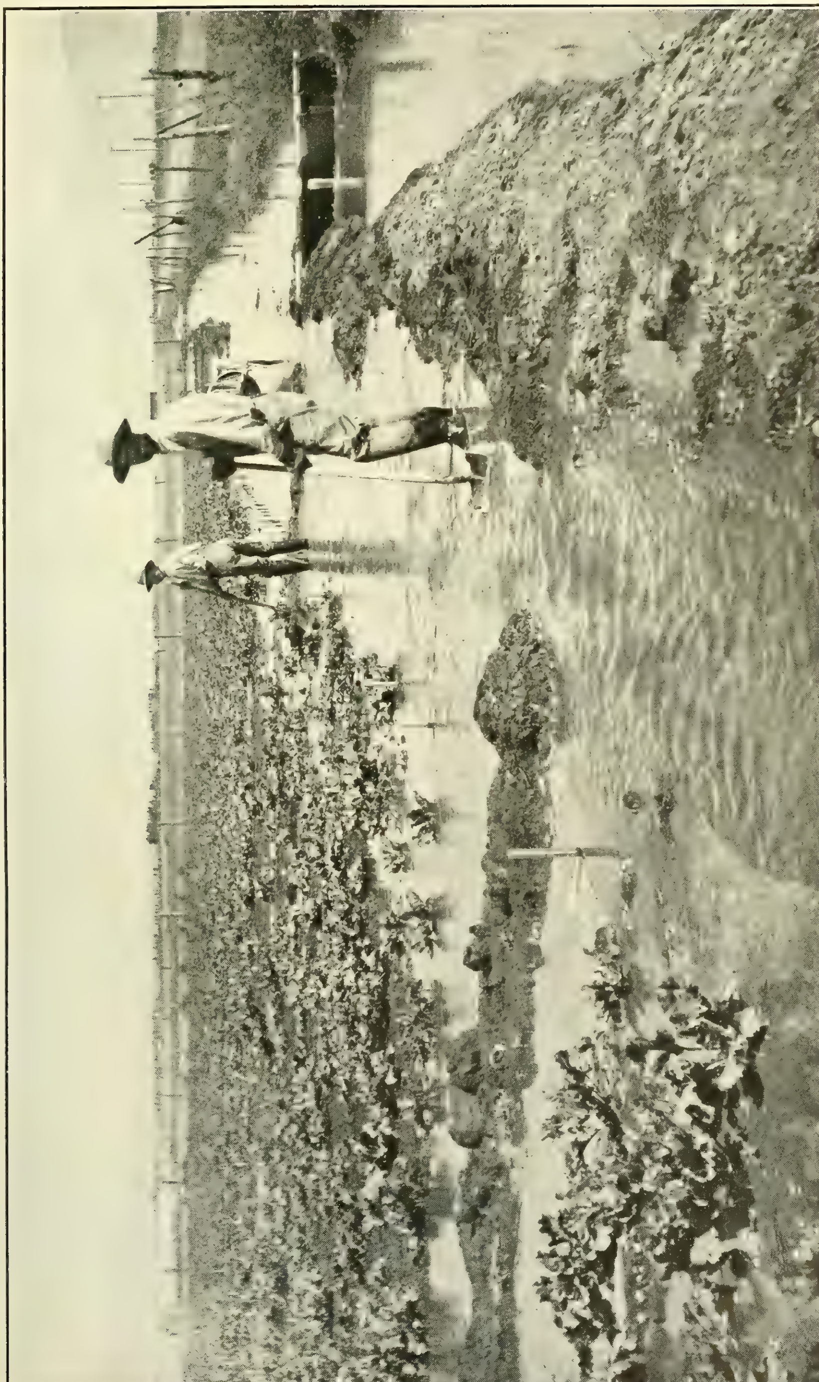


FIG. 2.—A DEEP-PLOWED BEET FIELD.

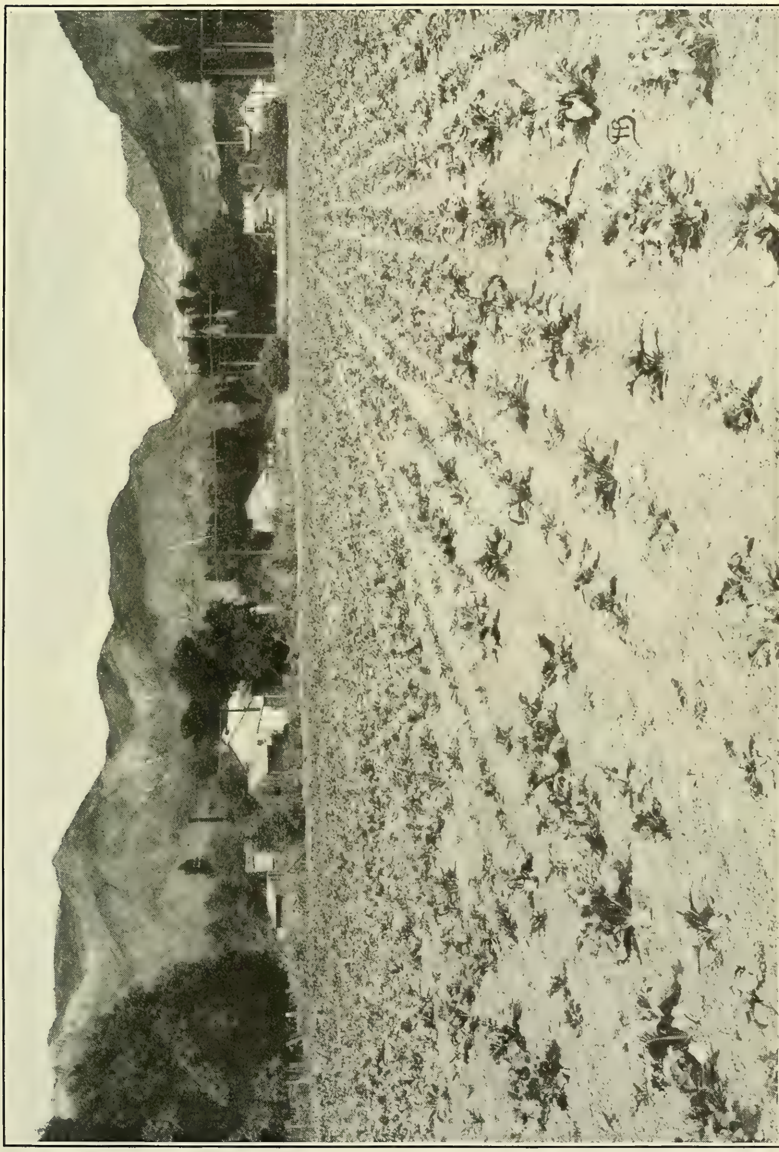
CONTIGUOUS SHALLOW-PLOWED AND DEEP-PLOWED FIELDS, SHOWING THE EFFECT OF EACH METHOD ON WEEDS.

Shallow plowing leaves the weed seeds near the surface, where they spring up before the beet seeds, checking and choking the young beet seedlings. Deep plowing buries the weed seeds and gives the beets an opportunity to get started before they come up.



A Poorly Leveled Beet Field that Involves Much Unnecessary Labor during Irrigation, and which Allows the Beets to be Killed on the Flooded Low Spots.

A Field of Sugar Beets, Showing the Gaps Left in the Rows by a Drill which Failed to Adjust Itself to the Irregularities in the Surface of the Ground.



A STAND OF SUGAR BEETS MUCH REDUCED BY DAMPING-OFF.

A HOMEMADE ROLLER USED TO COMPACT THE SOIL ABOUT THE ROOTS OF SEEDLINGS AND TO BREAK UP THE CRUST THAT SOMETIMES FORMS AFTER EARLY SPRING RAINS.

YOUNG SUGAR BEETS INJURED BY WIREWORMS.

The worm shown at the right is twice natural size.

A FIELD OF SUGAR BEETS, SHOWING THE EFFECTS OF LATE THINNING.

A, Thinned at the proper time; *B*, just thinned, several weeks after the first plat; *C*, not yet thinned and badly choked with weeds.

necessary to grade and level a field properly could be put in at odd times during the autumn and winter and in many cases would not cost more than the additional labor and loss entailed each season by leaving this work undone.

Implement manufacturers should be urged to study the improvement of seed drills in order to make them more responsive to the surface of the ground and to perfect a seed-dropping device for them. However, much of the trouble with seed drills could be avoided by better preparation of the seed bed.

The first cultivation, taking place soon after the seedlings appear, is sometimes carelessly done or is performed with implements not well adapted to the operation. Thus, many seedlings are smothered by having the soil thrown over them. A special type of cultivator, with disks adjusted to protect the plants, will prevent losses of this sort (fig. 5).

FIG. 4.—Sugar-beet seedlings, showing the effect of late frosts and the bites of flea beetles. The dead seedlings were killed by frost; the others were bitten by flea beetles.

LOSSES ON THE THINNING STAND.

Many beet growers defer thinning and spacing too long. The European beet growers hasten to their fields as soon as most of the seedlings have acquired two pairs of true leaves. To delay beyond this stage may mean a marked reduction in tonnage and sugar, as is shown by an experiment in Germany in which the results given in Table V were obtained.[1]

TABLE V.—*Losses due to delayed thinning of sugar-beet seedlings in Germany.*

Thinned—	Yield.	Loss per acre at $5 a ton.
	Tons.	
At the proper time	15	....
One week later	13.5	$7.50
Two weeks later	10	25.00
Three weeks later	7	40.00

[1] Robertson-Scott, J. W. Sugar Beet: Some Facts and Some Illusions, p. 120. London, 1911.

In general, the larger the plants when thinned the greater the shock they receive, and the weeds meantime have an opportunity to outstrip the beets, crowding and checking them. (Pl. VIII.)

However, the greatest single cause of deficiency in stand is careless or improper spacing and thinning. As shown in column 16, Table II, the average loss entailed in the plats under observation was 21.41 per cent. It is significant that this dual operation, one of the most expensive in beet culture, is very frequently done by contract labor either without supervision or with the most perfunctory and intermittent kind of supervision. In European beet fields this operation is under constant supervision.

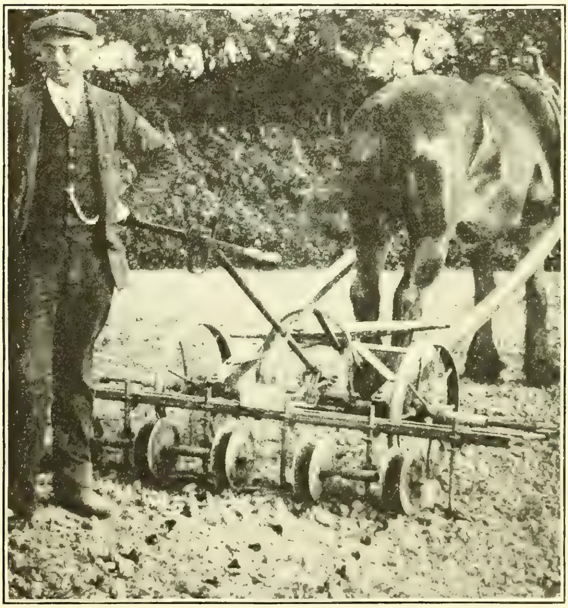


FIG. 5.—A beet cultivator with disks to prevent the seedlings from being covered by the earth thrown up by the cultivator blades. (Courtesy of J. W. Robertson-Scott, London, 1911.)

The deficiency of stand caused by this operation is brought about by spacing the plants too far apart, by leaving two or more plants together, or by carelessly chopping out plants where they should be left. In no instance has the writer been able to find the spacing as close as the beet grower intended or imagined. An increase of 2 or 3 inches in the distance between all the plants would greatly reduce the yield per acre, other things being equal. This excessive spacing is generally unsuspected and imperceptible except by actual measurement.

Yet one can scarcely blame hired or contract laborers for hurrying over this work, because in most cases they are paid the same price per acre whether the work be well or badly done and whether the stand be good or poor. It would seem but equitable to offer a bonus for better work, based on the number of plants per acre remaining after thinning. On the celebrated farm of Sainte Suzanne, belonging to the Prince of Monaco—a farm worked on scientific principles—it is required that the beets be left 11 inches apart in the row. About 40 cents additional per acre is paid if 28,000 beets an acre remain after the second cultivation.

The highest percentage the writer has attained by the careful use of a 6-inch hoe was 92.58 per cent for one row. His best average for 8 rows was 83.7 per cent, when working with moderate rapidity.

ELIMINATION OF HAND SPACING.

Although it is believed that the singling of beets will never be accomplished with machines or implements, it is thought to be entirely practicable to effect the spacing in such a manner.

In this country of high-priced labor, means should be devised to eliminate hand labor from farming operations as far as possible. Much has been accomplished already toward the successful pulling and topping of beets by machinery. A number of machines for blocking beets have been patented, and some of them are in successful operation. In some parts of Europe a 4-row or 6-row cultivator is run across the field at right angles to the rows, thus cutting out spaces at regular intervals. Generally, this spaces the beets too widely. Numerous attempts have been made in the United States to accomplish proper spacing by transplanting sugar-beet seedlings in the manner that tobacco, cabbage, celery, etc., are successfully set out. However, it has been thought that this causes the beets to become sprangling, by injuring or turning up the taproots of the young plants.

LOSSES AFTER THINNING AND BEFORE HARVESTING.

Individually, the losses occurring between the times of thinning and harvesting are of minor importance, although they aggregated 6.82 per cent among the plats under observation during the season of 1912. (See Table II, column 17.) A source of loss present every season, especially among less experienced beet growers; is that arising from the careless or unskilled use of the cultivator, not only when turning at the ends of rows, but in the rows themselves, by allowing the cultivator to swerve far enough to cut out plants. With a 2-row or 4-row cultivator this may occasion a serious loss, because two or four rows are injured simultaneously. It need only be said that a little more care would appreciably reduce this loss.

The later in the season that the various depletions in stand are made, the more serious is their effect on the yield, because the plants then have less chance to respond to space effect by an additional increase in size.

LOSSES FROM THE DRYING OF BEETS.

Another scarcely suspected loss, not due to deficiency of stand, often takes place at harvest. This is caused by leaving the beets in open rows or piles in the field after they have been dug. As soon as the roots have been torn from the soil, rapid loss of water takes place from every portion of the plant. Therefore, whether the beets

are left untopped or are topped and thrown in small piles or windrows, according to custom, the wind and sunshine cause the beets to lose weight. It has been shown that the loss in weight so occasioned may exceed 5 per cent a day for several days in succession, the percentage of loss gradually decreasing as the water is progressively withdrawn from the beets.

This circumstance could be taken advantage of when beets are dug which are found not to have attained the required percentage of sucrose. The water is withdrawn by evaporation, but the sugar is not. Therefore, a concentration of sugar would take place in consequence of the evaporation of a portion of the water by permitting the beets to dry out through exposure in the field after digging. This, doubtless, would soon be sufficient to augment the sugar percentage to the required degree.

SUMMARY.

A striking variation in the yield of sugar beets on the different farms in any particular beet district of the United States, even though of very restricted area, may be noted every season.

Since the climatic factors are practically uniform in such a restricted area or district, with cultural methods almost identical and soil types within that area not very diverse, additional causes for these great variations in yield are to be sought.

Employing as a basis for comparison the stand which experiment and experience have shown to be the optimum—subject to some modification for different soil conditions—namely, a stand containing 39,200 plants per acre, which would result by leaving beets 8 inches apart in rows 20 inches apart, these studies show that even among experienced beet growers, many of them truck growers, deficiencies in stand exist to an extent quite unsuspected.

These deficiencies of stand may be divided into three groups: (1) Those occurring in the germination stand, averaging 19.32 per cent among the plats of 1912; (2) those due to improper spacing and thinning, averaging 27.3 per cent among the plats of 1911 and 23.27 per cent in 1912; and (3) those occurring between thinning and harvest, ranging from 2.54 to 12.85 per cent, with an average of 7.26 per cent among the 18 plats from which these data were obtained. Together these represent a total mean deficiency of stand of more than 50 per cent.

Most of these losses in stand can be greatly reduced by the application of better methods or a more careful adherence to already existing ones, by the more thorough supervision of hired labor, and by the elimination of contract work as far as possible. The losses may be considered as largely the result of inexperience and inefficiency. This is emphasized by the fact that as a rule where losses from one source are great, those from other sources are correspondingly large.

The data here presented show a strong correlation between percentage of stand and yield. The existence of a relation between yield and percentage of stand has been demonstrated frequently under experimental conditions in Europe and rather less frequently in the United States. Therefore, it is believed that the losses in stand shown to take place progressively throughout the season correspond to a loss in yield. However, it is also shown, through apparent exceptions to this correlation, that despite a stand of fair percentage at the outset the yield may remain comparatively small through neglect and carelessness during the season.

There is found to be a moderate uniformity in methods, but great irregularity and discrepancy are conspicuous in the thoroughness of their application; in other words, efficiency varies greatly.

It is not to be expected that every beet grower, although he may possess fields well adapted to beet culture, can at once obtain such yields as the best of those mentioned in this paper. However, such yields should be possible on many farms when, after a few years of thorough cultivation, the fields have been worked up into equally good condition. The benefits accruing from increased yields of beets through improved tilth of the soil are especially pronounced.

These studies were made among fair and good beet growers in an old beet district whose mean yield reached the respectable total of rather more than 17 tons to the acre, while the average for the United States for 1910–11 was only 10.17 tons and that for the State of Utah, where these studies were made, was 11.42 tons per acre. The magnitude of preventable loss incurred by a very large proportion of beet growers must be amazing; in fact, it must exceed the entire cost of raising the crop.

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 239

Contribution from the Bureau of Entomology, L. O. Howard, Chief.

June 24, 1915.

(PROFESSIONAL PAPER.)

THE EGGPLANT LACE-BUG.[1]

By

David E. Fink,

Entomological Assistant, Truck Crop and Stored Product Insect Investigations.

(In cooperation with the Virginia truck experiment station, Norfolk, Va.)

INTRODUCTION.

Injury to eggplant by lace-bugs (Pl. I) first attracted the attention of the writer during the spring and summer of 1913. In the vicinity of Norfolk, Va., eggplant was found to be infested by a species at that time undescribed. It proved to be *Gargaphia solani* n. sp., the designation being given by Mr. Otto Heidemann, of the Bureau of Entomology. Owing to pressure of other work during the season of 1913 no further attempts were made at the time to study the insect to any great extent, but it was noted to feed extensively on eggplant, the leaves of which turn yellow and finally shrivel up. During the spring and summer of 1914 it again came under observation, investigation proving it to be widely distributed in Tidewater Virginia. In fact, wherever eggplant was grown on a commercial scale the lace-bugs were feeding. It was then considered advisable to make a careful study of the habits of this insect in view of its wide economic importance, and at the same time to devise and test methods for its control.

NATURE OF ATTACK.

In the early nymphal stages lace-bugs resemble the young of aphides; and since they procure their food by suction, the injury resulting to the plants (Pls. II, III) is indicated by a characteristic yellowing of the leaves. All stages may be found on the underside of the leaves, and in the nymphal stages, particularly, they always feed in original colonies as hatched. The first stage of injury appears in the form of circular discolored areas of about the size of a silver quarter. Such a leaf when examined will show a mass of eggs, and

[1] *Gargaphia solani* Heidemann.

Note.—This bulletin deals with a new enemy of eggplant and related plants. It will be of interest wherever these plants are grown commercially.

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usually the female also will be observed either in close proximity feeding or in the act of ovipositing. Upon the emergence of the nymphs from the eggs the discoloration of the leaves increases in area until finally the entire leaf is involved, turning yellow and dry.

The nymphs migrate from one leaf to another, injuring every leaf attacked, until they transform, after which, as adults, they disperse to other plants. Not every plant in a field will be injured, but once a plant becomes infested every leaf may be so injured as to result in the loss of the plant.

The truckers in the vicinity of Norfolk, Va., usually raise eggplant in fields of from 6 to 10 acres. During the summer of 1914 many such fields were carefully examined, and the injury was estimated at from 10 to 15 per cent of the entire acreage. The uninformed trucker does not as yet recognize this insect as a specialized eggplant pest, since the injury closely resembles that due to aphides. As the plant-lice are feeding on the eggplant at about the same time, the lace-bug injury is usually attributed to them. The injury to eggplant by this tingitid is entirely well defined and individual in character, and no one who has carefully observed the damage would ever confuse it with that due to the work of aphides.

DESCRIPTION OF STAGES.

THE ADULT.

This interesting lace-bug belongs to the heteropterous family Tingitidæ, which contains a number of injurious forms affecting certain of our native trees and shrubs. Although many species are found in some tropical countries, those occurring in the United States are comparatively few in number.

The eggplant lace-bug is one of the larger species of the United States and differs considerably in appearance from the others by reason of its prominent lacelike hood extending back of the head and the lacelike venation of the wings. The adult (Pl. I, fig. 2) is depressed or flat bodied, grayish to light brown, about 4 millimeters ($\frac{3}{16}$ of an inch) in size, and derives its popular name from the delicate lacelike structure of the wing covers.

Following is a technical description of the adult by Mr. Otto Heidemann:[1]

Body rather flat; dark brown; angulated; yellow rim of the rostral groove very distinct at base of metasternum. Head dark, deeply punctured; at frontal part three small slender spines, the upper one more prominent; two others near to the eyes a little longer. Antennæ quite long, hairy; basal joint comparatively thick, black, and somewhat longer than the terminal joint, which is fusiform and black at the apex; second joint the shortest, testaceous; third more than four times as long as the fourth joint, yellowish white; bucculæ moderately expanded, yellowish, with one row of minute areoles.

[1] Heidemann, Otto. A new species of North American Tingitidæ. *In* Proc. Ent. Soc. Wash., v. 16, no. 3, p. 136–137, 1 fig., Sept. 26, 1914.

Pronotum feebly convex, black, with three low yellowish carinæ, the median one a little higher before the middle, tapering toward the pale apex of the triangular posterior portion of the pronotum; the lateral membranous part of the pronotum angularly expanded, with two to five series of irregular areoles, the edge somewhat broadly reflexed, some of the nervures exteriorly blackish. Head, pronotum, and the edge of the membranous dilation densely covered with fine, soft hairs; pronotal hood rather large, much longer than wide, covering the hind part of the head, leaving the eyes free; surface yellowish white, opaque, with fine minute areoles. Hemelytra extending about one-third beyond abdomen; oblong-oval, broadly rounded at the end, feebly sinuate toward the base; the discoidal areas pyriform, reaching to about the middle of the elytra, reticulated, blackish at base and at apex, a pale stripe across the middle, the subcostal biseriate, yellow; costal margin yellowish-white, translucent with four or five series of medium-sized areoles at the widest part, those toward the base smaller; five transverse oblique nervures black at the costal area and all nervures at the apex more or less blackish. Legs pale, yellow. Length, 4 mm.; width, 2 mm.

The following descriptions of the immature stages are by the writer:

THE EGG.

Length 0.37 mm., width 0.18 mm. Color light to dark greenish at base, gradually assuming brownish toward the apex. Top of egg crater-like, with whitish lacelike border, and screwlike rim. The entire egg resembles a miniature bottle. The eggs are attached to the underside of the leaves by their bases and usually lean in all directions and at almost every angle.

THE NYMPHAL STAGES.

First stage.—Length 0.3 to 0.4 mm, width 0.12 mm. The newly hatched nymph resembles a newly born aphis, is white to light yellow, with pink eyes, long legs, and antennæ as long as body.

Second stage.—Length 0.8 mm., width 0.19 mm. Color yellow. Antennæ as long as body; the last segment clublike, covered with setæ; last segment of the legs possessing a pair of claws. There are spines on each side of the thorax and from each segment of the abdomen.

Third stage.—Length of body same as in the previous instar; width decidedly more, 0.30 mm. Spines on lateral margin and on dorsal surface of body. First indications of wing pads occur in this stage by the swelling of lateral margins of the thorax.

Fourth stage.—Length 1.5 mm., width 0.8 mm. Body oblong-ovate, yellowish. Head dark yellow, hood prominent; wing pads extending to second abdominal segment. Entire body covered with spines, the position of which is discussed in the following nymphal stage. Antennæ as long as body, light brown.

Fifth stage.—Length 2.2 mm., width 1.2 mm. (Pl. I, fig. 2.) Body oblong-ovate, yellowish except at margin of abdomen, where it is light yellow with dark patch at the apex. On the lateral margins of each side of first three abdominal segments a tubercle rises directly from the surface, and from the last six abdominal segments rise prominent spiny processes. From the middle of each of first and second abdominal segments there rise two hornlike spiny processes, and one from the fourth, fifth, and seventh segments dorsally. One spiny process and some tubercles on the lateral margin of the wing pads; two large spiny processes placed near together on the metanotum, and tubercles at each side of thorax. On each lateral margin of the hood there is a spiny process and some tubercles; two prominent spines are located centrally, and a small pair nearer the head. The head carries three strong spines in front, one long and two shorter ones; two large, strongly curved, hornlike spines at the base near the eyes. All spiny processes except on the lateral margins of the sixth, seventh, and eighth abdominal segments dark brown; those on latter light yellowish. Head yellowish brown; eyes prominent; thorax dark yellow; wing pads light yellowish with dark margin at base, extending to fifth abdominal segment. Antennæ light brown, as long as body.

DISTRIBUTION.

The collection of Tingitidæ at the U. S. National Museum contains few specimens of this species. These have been recorded by Mr. Heidemann in his paper as follows: Kirkwood, Mo., August 10 (Riley, Pergande), found on *Solanum carolinense* and *Solanum elaeagnifolium;* Lavaca County, Tex., June 21; Columbus, Tex., July 29, 1879 (Riley collection), on coffee weed (*Cassia* sp.) and *Solanum* sp.; El Reno, Okla., July 12, 1909; Norfolk, Va., June 12, 1913 and 1914 (Fink), and the author stated at the time "It is recorded as found on eggplants in great abundance." The species was also found by Dr. F. H. Chittenden, August 12, 1913, and later, and by others, including the writer, in the District of Columbia, and by the writer in Maryland and at Occoquan, Va. Judging from the localities already known it is a native American species and seems to have a range of distribution extending from the South Atlantic coast to the Southwestern States.

SEASONAL HISTORY.

THE ADULTS.

Early in spring, almost as soon as eggplants are set in the field, the hibernating adults begin to infest them and establish colonies. Thus adults and eggs were found as early as May 20. The adults reproduce and feed the entire summer on the eggplant, but migrate to the horse nettle (*Solanum carolinense*) during the latter part of August and the first week in September, when the season for eggplant is about over. Here they continue breeding until cold weather sets in. The adults hibernate in the shriveled leaves or in the ground under débris, reinfesting the next crop when set out.

The egg-laying period in the field lasts from four to five days. In the laboratory the duration is slightly longer, the temperature averaging 75° F. Table I indicates the date and number of eggs deposited by three females confined in the laboratory.

TABLE I.—*Number of eggs deposited by females of the eggplant lace-bug, Norfolk, Va., 1914.*

Female A.		Female B.		Female C.	
Date.	Number of eggs.	Date.	Number of eggs.	Date.	Number of eggs.
June 16	57	June 24	30	July 12	28
June 18	30	June 25	41	July 13	31
June 20	34	June 27	23	July 15	42
June 22	44	June 29	23	July 19	15
June 24	23				
Total	188		117		116

Females that were observed in copulation on July 12, 1914, gave the first complement of eggs July 14, 1914.

FIG. 1.—LAST NYMPHAL STAGE OF THE EGGPLANT LACE-BUG. GREATLY ENLARGED. (ORIGINAL.)

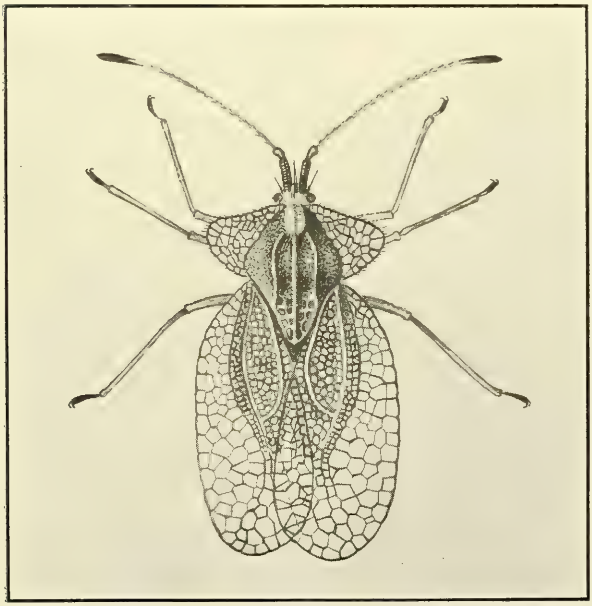


FIG. 2.—ADULT OF THE EGGPLANT LACE-BUG. GREATLY ENLARGED. (ORIGINAL.)

THE EGGPLANT LACE-BUG (GARGAPHIA SOLANI).

SURFACE OF EGGPLANT LEAF, YELLOW AND DRY AS A RESULT OF LACE-BUG ATTACK. (ORIGINAL.)

WORK OF THE EGGPLANT LACE-BUG.

UNDERSIDE OF EGGPLANT LEAF INJURED BY LACE-BUGS. (ORIGINAL.)

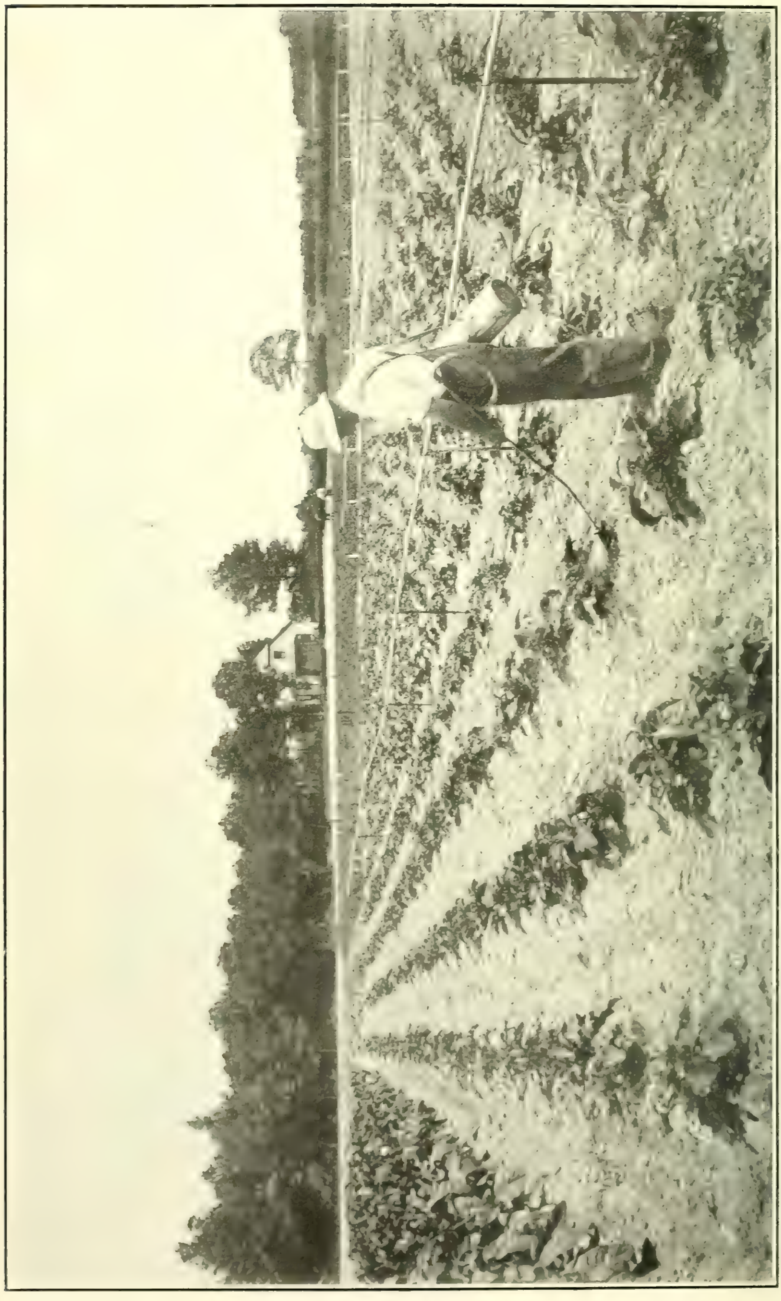
WORK OF THE EGGPLANT LACE-BUG.

UNDERSIDE OF LEAF OF EGGPLANT WITH ALL STAGES OF THE LACE-BUGS. (KILLED BY FISH-OIL SOAP, 7 POUNDS, TO 50 GALLONS OF WATER. NORFOLK, VA., 1914.) (ORIGINAL.)

WORK OF THE EGGPLANT LACE-BUG.

LAST NYMPHAL STAGE OF THE EGGPLANT LACE-BUG ON UNDERSIDE OF EGGPLANT LEAF. NORFOLK, VA., 1914. (ORIGINAL.)

THE EGGPLANT LACE-BUG.



SPRAYING EGGPLANTS FOR THE EGGPLANT LACE-BUG. NORFOLK, VA. (ORIGINAL.)

THE EGGPLANT LACE-BUG.

THE EGGS.

The minute greenish eggs are deposited on the underside of the leaves in circular masses of about 116 to 188. Their bases are attached in irregular rows, not erect, but, as before stated, leaning in different directions and at different angles. A sticky secretion is spread over the eggs after oviposition. To the unaided eye the eggs appear like a mass of mere dots on the underside of the leaf, occupying an area of leaf surface about one-half inch in diameter. The female attends the eggs during the entire period of incubation, leaving them only at intervals to feed, and later, when the nymphs emerge, is constantly in attendance.

Table II indicates the normal period of incubation for the summer months. Since not all the eggs are deposited at one time by the female, the emergence of the nymphs extends over several days. The table, however, refers to dates when nymphs first began emerging.

TABLE II.—*Incubation period of the eggplant lace-bug, Norfolk, Va., 1914.*

No.	Date of deposition of eggs.	Date of emergence of nymphs.	Incubation period.	No.	Date of deposition of eggs.	Date of emergence of nymphs.	Incubation period.
			Days.				*Days.*
1	May 24	May 30	6	6	June 23	June 28	5
2	May 25	May 31	6	7	June 23	June 29	6
3	June 15	June 23	8	8	June 26	July 3	7
4	June 17	June 24	7	9	July 4	July 19	5
5	June 21	June 26	5				

THE NYMPHS.

The nymphs are always found feeding in groups (Pls. IV and V). After the first molt they become yellow and at the same time shift their feeding position on the leaves. When migrating from one leaf to another the female adult usually directs the way, and with her long antennæ keeps the nymphs together or rebukes any straggler or deserter. It is an interesting sight to observe the migration of a colony of more than a hundred nymphs, with the female adult hurrying from one end of the flock to the other, keeping them together, and at the same time urging them in the right direction during the migration. When a new area has been selected the nymphs settle down, insert the proboscis, and begin to feed.

In its undeveloped forms, particularly in its last two nymphal stages, the eggplant lace-bug is an interesting and grotesque-looking object. The head and body are covered with spiny processes the function of which is not yet well understood. Some of the spines on the head are hornlike and, situated as they are near the eyes, they resemble very much the horns of some domesticated animals.

That the adult female keeps a watchful eye for intruders and enemies while in attendance on the nymphs is attested by the following

observation: On one occasion while observing the feeding of the nymphs a ladybeetle (*Hippodamia convergens* Guer.) was seen to approach the brood, when the adult lace-bug in attendance on the nymphs, with outstretched, slightly raised wings, suddenly darted toward the intruder, driving it from the leaf.

From the time the nymphs are born until they reach the adult form they pass through five distinct molting periods, and when temperature and other conditions are normal the time between molts is quite constant. From Table III it will be observed that two days is the usual period between molts.

TABLE III.—*Molting stages of nymphs of the eggplant lace-bug, Norfolk, Va., 1914.*

No.	Date hatched.	First molt.	Second molt.	Third molt.	Fourth molt.	Fifth molt.	Adult.
1		July 9	July 11	July 13	July 15	July 17	
2		...do.....	...do.....	...do.....	...do.....	...do.....	
3		...do.....	...do.....	...do.....	...do.....	...do.....	
4		July 10	July 12	July 15	July 17	July 18	
5	July 7	July 9	July 11	July 13	July 15	...do.....	Adult.
6		...do.....	...do.....	...do.....	...do.....	July 17	
7		...do.....	...do.....	...do.....	...do.....	...do.....	
8		...do.....	...do.....	...do.....	Dead.	...do.....	
9		...do.....	...do.....	...do.....	July 15	...do.....	

LIFE CYCLE AND NUMBER OF GENERATIONS.

Since two days represents the duration of time between molts, the life of the nymph from the egg to the last nymph, under normal conditions, is 10 days. Allowing six days for the egg stage and several days for time before and after copulation by adults, the life cycle is approximately 20 days.

In the vicinity of Norfolk, Va., this lace-bug was found breeding as late as November, giving a breeding season of nearly six months. There is a possibility of from seven to eight generations a season. Apparently six generations are spent on eggplant and the remainder on horse nettle.

Most of the generations in the field overlap, and the following observations made during the summer of 1914 indicate that six generations are spent on eggplant.

First generation, May 24.
Second generation, June 11.
Third generation, July 7.
Fourth generation, July 26.
Fifth generation, August 15.
Sixth generation, September 4.

In the region of Norfolk, Va., as stated before, the growing season for eggplant ends about the last of August or the first week in September, after which the lace-bug is found on the horse nettle (*Solanum carolinense*), where it continues to feed. It undoubtedly produces several generations on this plant, for as late as November all stages of the insect, including eggs, were found on it.

NATURAL ENEMIES.

Several predaceous insects were observed feeding on the nymphs and adults of the eggplant lace-bug. The species of ladybeetles common in this section, *Hippodamia convergens* Guer. and *Megilla maculata* De Geer, in both the larval and adult forms feed on the nymphs and adults of this lace-bug, usually turning them over on their backs before feeding. A common soldier-bug, *Podisus maculiventris* Say, feeds on the nymphs. Another common hemipteron found feeding on the nymphs is *Triphleps insidiosus* Say. Three species of spiders, *Epeira domiciliorum* Hentz, *Plectana stellata* Hentz, and *Chiracanthium inclusum* Hentz, identified by Mr. Nathan Banks, of the Bureau of Entomology, were observed feeding on all stages of the lace-bugs. It was not uncommon to find many lace-bugs with the head severed and the body mutilated. A very few specimens of a hymenopterous parasite were reared with the adult lace-bugs; this was identified as *Microdus* sp.[1] but it was not positively proved to attack the lace-bug.

METHODS OF CONTROL.

June 17 and 18, 1914, a series of spraying experiments against this lace-bug was undertaken in which the comparative values of fish-oil soap and various strengths of a standard blackleaf tobacco extract containing 40 per cent active nicotine sulphate were tested. (See Plate IV.) The results were quite satisfactory.

TABLE IV.—*Spraying experiments against the eggplant lace-bug, Norfolk, Va., 1914.*

No.	Fish-oil soap.	Nicotine sulphate.	Nymphs killed (per cent).	Adults killed (per cent).
1	1 pound to 50 gallons of water	1 to 1,066	80 to 85	None.
2	do	1 to 800	90	None.
3	do	1 to 640	85 to 90	None.
4	2½ pounds to 50 gallons of water		80 to 85	None.
5	3 pounds to 50 gallons of water		90	None.
6	5 pounds to 50 gallons of water		95	None.
7	6 pounds to 50 gallons of water		100	40 to 50
8	7 pounds to 50 gallons of water		100	90 to 95
9	8 pounds to 50 gallons of water		100	95

From the above table it will be readily seen that the percentage of nymphs killed was but slightly affected by the increase in the amount of the nicotine sulphate, and that the latter had no effect whatever on the adults; whereas with each increase in the amount of fish-oil soap there was a corresponding increase in the percentage of nymphs killed, until finally we arrive at a strength which will affect the adults. Above that strength we may then get perfect control of both the nymphs and adults.

Too much emphasis can not be laid on the thoroughness with which the spraying should be performed. It is particularly essential that the underside of the leaves be thoroughly covered by the spray.

[1] Chttn. No. 1373[01].

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 240

Contribution from the Bureau of Animal Industry
A. D. MELVIN, Chief

Washington, D. C. PROFESSIONAL PAPER July 13, 1915.

PASTEURIZING MILK IN BOTTLES AND BOTTLING HOT MILK PASTEURIZED IN BULK.

By S. Henry Ayers, *Bacteriologist*, and W. T. Johnson, Jr., *Scientific Assistant, Dairy Division.*

CONTENTS.

INTRODUCTION.

The process of heating milk in bottles is by no means a new one, for it probably dates back to the work of Soxhlet (1),[1] from 1886 to 1891. In general, however, the object has been partially or completely to sterilize the milk by the use of high temperatures rather than simply to pasteurize it at low temperatures. While the practice of sterilizing or partially sterilizing milk in bottles has been extensively practiced in several countries in Europe, the pasteurization of milk in bottles has not been so common.

[1] The figures in parenthesis refer to the list of citations to literature at the end of the paper.

NOTE.—This paper is of interest to milk dealers, health officials, and all who have to do with the milk supply of cities; it is suitable for distribution in all parts of the country.

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It is evident from the report of Gerber and Wieske (2) that pasteurization in bottles has been practiced in certain localities for a considerable period of time. According to these authors, pasteurization in bottles by the process of Gerber, which consists of heating milk in bottles for one hour at 65° C. (149° F.), during which they are agitated, had been practiced in certain dairies for 15 years previous to 1903.

In this country milk has been pasteurized directly in bottles at various Strauss infant milk stations for several years, but this process has not been used on an extensive commercial scale until within the last two years. During the summer of 1910 an investigation was started of the bacteria which survived pasteurization in flasks and of the efficiency of the process. A report of this work has been published in Bulletin 161 of the Bureau of Animal Industry (3).

While this work was in progress North (4) suggested the pasteurization of milk in bottles on a commercial scale by the use of machines similar to those which have been in use in breweries for several years.

The process of pasteurizing in bottles consists in bottling the milk in specially constructed bottles of sufficient size to allow a space in the top of the bottle to take care of the expansion of the milk during heating. The bottles are capped with special water-tight caps and submerged in hot water. After the milk in the bottles has reached the pasteurizing temperature, the temperature is maintained for 30 minutes; the hot water is then replaced by cold and the milk cooled. In general it takes about 30 minutes to heat the bottles, 30 minutes for the holding period, and 30 minutes to cool. Milk is also pasteurized in the bottle by heating and cooling with water which is sprayed over the bottles. By this method of spraying, ordinary caps with a protective covering can be used; this will be described in another place in this bulletin.

This process of pasteurizing in bottles is now used on a commercial scale in a number of milk plants throughout this country.

Numerous advantages of this method of pasteurization over the ordinary methods have been claimed particularly in relation to the far superior bacterial reductions obtained. The most obvious point of advantage of this process is the prevention of reinfection after pasteurizing, but it seems as though a modification of the present system of "holder" pasteurization by bottling the pasteurized milk while hot, as suggested previously by the senior writer (5), would help to solve the problem of reinfection.

Accordingly, the general object of the work hereinafter described has been to compare on a laboratory scale pasteurization in bottles with the process of bottling hot pasteurized milk. The special objects have been to determine the bacterial reductions in each process, to study any special points which must be considered in the opera-

tion of each process, and to present preliminary data on the cooling of milk in bottles by an air blast.

METHOD OF BACTERIOLOGICAL ANALYSIS.

Since bacterial counts are widely influenced by differences in media and incubation it is always essential in discussing the results of bacteriological work to explain exactly how the counts were obtained. In this work plain infusion agar, made according to the recommendations of the committee on milk analysis (6), was used. The plates were incubated for five days at 30° C. (86° F.) and counted.

METHOD OF PASTEURIZING IN BOTTLES.

Milk was placed in special bottles, similar to those supplied to the trade, and capped by machine with patented metal caps. The bottles were heated by being submerged in hot water at a temperature of from 145° to 147° F. After the temperature in the bottom of the bottles had reached 145° F. they were held at that temperature for 30 minutes and removed, plates being made while the milk was hot. The bottles were so constructed that after a full quart of milk was poured in there remained an air space of sufficient size to allow for the expansion during the heating. While heating it was noticed that the milk expanded and pressure enough was generated to lift the caps slightly so as to allow air to escape. Special care was taken to see that the temperature in the bottom of the bottle of milk was maintained for the full 30 minutes.

The method of pasteurization was the same as is used on a commercial scale; hence, the results obtained are directly applicable to commercial conditions. The fact that the bacterial counts were taken directly after heating has no effect on the results, since it has been shown that cooling plays no part in the destruction of bacteria in the pasteurizing process (3).

BACTERIAL REDUCTIONS BY PASTEURIZATION IN BOTTLES.

It has been claimed that remarkable bacterial reductions have been obtained by pasteurization in bottles which were far superior to those obtained by other methods even when the same temperature and holding period were used. In order to determine what reductions could be obtained, 34 samples of milk were pasteurized in bottles.

The results are seen in Table 1. The bottles for samples Nos. 2 to 23, inclusive, were washed clean in hot water, but not steamed, before they were filled with raw milk. The bottles for the other samples were steamed two minutes and then cooled before they were filled with raw milk.

TABLE 1.—*Bacterial reductions during the process of pasteurization in bottles.*

Sample No.	Raw milk.	After pasteurization in the bottle for 30 minutes at 145° F.	Percentage reduction.	Sample No.	Raw milk.	After pasteurization in the bottle for 30 minutes at 145° F.	Percentage reduction.
	Bacteria per c. c.	*Bacteria per c. c.*			*Bacteria per c. c.*	*Bacteria per c. c.*	
2	58,000	1,630	97.18	20	80,000	2,010	97.48
3	63,000	1,070	98.30	21	160,000	29,500	81.56
4	5,100,000	11,800	99.76	22	151,000	12,500	91.72
5	580,000	8,000	98.62	23	81,000	9,800	87.90
6	5,900,000	15,600	99.74	24	24,900	570	97.71
7	99,000	980	99.01	25	94,000	2,200	97.66
8	7,400,000	7,100	99.90	26	305,000	55,800	81.70
9	191,000	7,600	96.02	27	235,000	7,600	96.76
10	14,100,000	14,200	99.89	28	176,000	11,400	93.52
11	24,700	5,780	75.59	29	97,000	8,350	91.39
12	75,000	28,000	62.66	30	230,000	5,500	97.61
13	126,000	1,720	98.63	31	124,000	1,500	98.79
14	4,100,000	2,410	99.94	32	450,000	11,400	97.46
15	76,000	3,550	95.32	33	3,950,000	3,520	99.91
16	8,100,000	1,660	99.98	34	985,000	18,400	98.13
17	18,900	710	96.24	35	190,000	9,300	95.10
18	24,000	10,900	50.41				
19	28,300	23,300	17.67	Average.	1,570,493	9,863	90.86

As may be seen from the table, the bacterial reductions were high as a rule, but there were exceptions. The average total count of the samples of raw milk was 1,570,493 and after pasteurization 9,863 bacteria per cubic centimeter. It is interesting to note that the percentage reductions averaged 90.86 per cent and ranged from 17.67 per cent to 99.98 per cent. When the latter reduction was obtained the raw milk contained 8,100,000 bacteria per cubic centimeter: when the minimum reduction was obtained the raw milk contained 28,300 bacteria per cubic centimeter. These results further substantiate the conclusion expressed in Bulletin 161, page 58 (3), that percentage bacterial reduction has no special meaning, since it is influenced by the number and kinds of bacteria in the milk when pasteurized. Considering the results as a whole, it is evident that low counts may be obtained by pasteurization in bottles.

While carrying on these experiments the following points were noted which are worthy of attention:

TEMPERATURE OF THE MILK DURING HEATING.

In the process of pasteurization it was found that the temperature of the milk in different parts of the bottle was quite different during the time the milk was being heated. Several experiments were made, heating water in sealed bottles to determine the differences in the top, middle, and bottom of the bottles. Three thermometers were inserted through a rubber stopper into a bottle so that the stems were at the top, middle, and bottom of the bottle, respectively. The bottles were then submerged in hot water at a temperature of from 145° to 146° F. and the temperatures of the water in the bottles were recorded.

Four pint bottles and four quart bottles were used. The averaged temperatures in the pint bottles are shown in figure 1. It will be seen from the curves that in a pint bottle with water at 50° F. submerged in hot water at about 145° F. it took 10$\frac{4}{5}$ minutes longer for the temperature in the bottom of the bottle to reach 140° F. after the top had reached that temperature and 4$\frac{3}{5}$ minutes longer for the temperature in the middle of the bottle. When the temperature in the top of the bottle was 140° F., in the bottom it was only 118° F.

The averaged temperatures of four quart bottles are shown in figure 2. When the temperature in the top of the bottle was 140° F., that in the bottom was only 127° F., and it took 9$\frac{1}{5}$ minutes longer for the temperature in the bottom to reach 140° F.

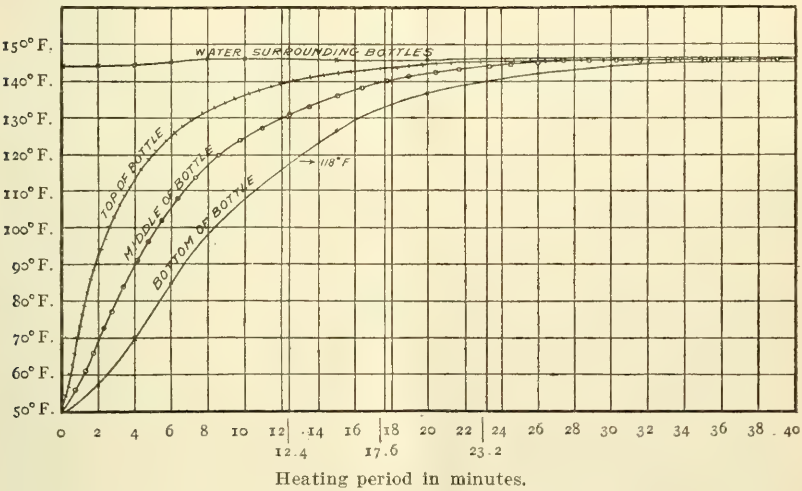

FIG. 1.—Variations in temperature in different parts of pint bottles of water during the process of pasteurization in the bottle.

It is evident that when pasteurizing in the bottle care must be taken to record the temperature in the bottom of a bottle and to date the holding period of 30 minutes from the time the bottom temperature has reached 145° F. In recording the temperature an accurate thermometer should be used, and it should reach to within one-half inch of the bottom of the bottle.

COOLING THE MILK AFTER PASTEURIZING.

After the milk is heated in bottles on a commercial scale it is cooled by replacing the hot water with cold and gradually changing the temperatures so as not to break the bottles. Upon cooling, the hot milk contracts and a partial vacuum is formed in the bottle when the caps are tight. It is recommended by the manufacturers of some of the patent caps that after heating the bottles be allowed to

cool for a few minutes in air until the cap becomes concave, as this is said to hold the cap on tight and helps to make it water-tight. Obviously, it is of utmost importance that the caps be water-tight, since they are submerged in water during cooling, and if not tight the milk may become infected by polluted cooling water.

When bottles are submerged the ordinary cardboard cap is of no value for pasteurization in the bottle, since water will easily penetrate during cooling. This makes it necessary to use some form of patented cap, of which both specially treated cardboard and metal caps are on the market. It is almost needless to state that if the edge of the bottle is chipped or otherwise imperfect almost any seal cap will not be water-tight during the cooling. Imperfect bottles must not be used. It is claimed by the manufacturers of patented seal

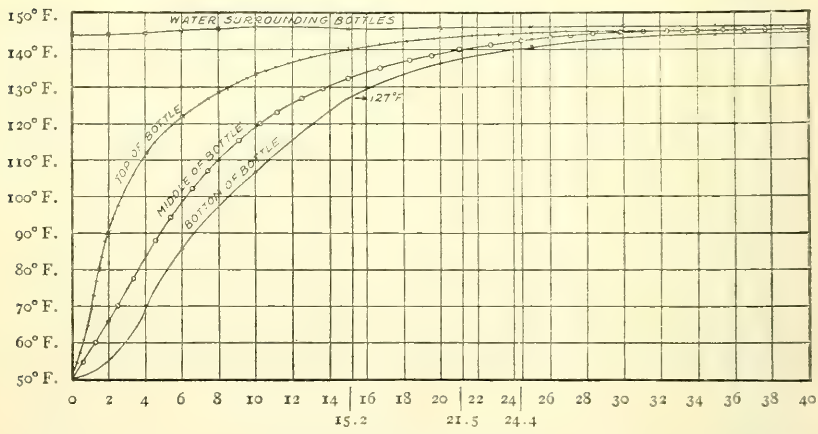

FIG. 2.—Variations in temperature in different parts of quart bottles of water during the process of pasteurization in the bottle.

caps that they are tight on perfect bottles. It would be advisable, however, for the dairyman to test the tightness of his caps by the following method: Fill the milk bottle with a 0.05 per cent solution of barium chlorid ($BaCl_2$). The barium-chlorid solution should be made up with distilled water, since the sulfates present in ordinary water will cloud the solution. Cap the bottles in the usual way with a seal cap and heat to 145° F., submerge, and cool in a 10 per cent solution of magnesium sulfate ($MgSo_4$).

If any of the magnesium sulfate leaks into the bottle during cooling the barium-chlorid solution will become cloudy, owing to the formation of barium sulfate, which is insoluble. This test is very delicate and will show even a slight leak. Both these chemicals may be obtained at any drug store. *Since barium chlorid is poisonous, after testing bottles in which it has been used care must be taken to*

wash the bottles thoroughly in order to remove the barium solution. Care must also be exercised to keep the chlorid solution from all edible products about the plant.

ADVANTAGES AND DISADVANTAGES OF PASTEURIZATION IN BOTTLES.

From a bacteriological standpoint the advantage of pasteurization in bottles lies in the fact that reinfection after pasteurization is usually prevented. In the ordinary methods of pasteurization there is a great opportunity for infection from coolers and in bottling. Of course the proper handling in the ordinary method of pasteurization reduces and may prevent subsequent reinfection, but the possibility still remains.

It is the general opinion that the process of pasteurization in bottles also effects a great saving in milk by doing away with the loss in evaporation over the coolers and with the loss in milk which adheres to the apparatus in the process of pasteurization. Undoubtedly this saving is quite a considerable factor. There may also be a saving in the expense of machinery and in the interest on the capital invested, but it is not the province of this paper to discuss the financial aspect of this process.

On the other hand, in a plant where pasteurization is now performed in the ordinary way, it would be necessary to install an entirely new equipment for this system of pasteurization in the bottle. When bottles are heated and cooled by submerging in water perhaps the greatest disadvantage is the cost of water-tight caps. This item of expense is important, since it may increase the cost of pasteurization as much as one-fifth of a cent per bottle. Whether the saving in milk losses is sufficient to overcome this added expense can be determined only by the actual operation of a milk plant. In some processes of pasteurization in the bottle ordinary caps can be used, as the bottles of milk are heated and cooled by a spray of water, and the tops of the bottles are protected by metal coverings.

MACHINERY FOR PASTEURIZING MILK IN BOTTLES.

Pasteurization in the bottle has been practiced on a commercial scale in many different ways since water-tight caps made it possible to heat milk in bottles by submerging in water. When this process of pasteurization was first practiced the bottles, with water-tight caps, were placed in tanks and heated, held, and cooled by changing the water. This method, while satisfactory on a small scale, was hardly practical in large plants. Several types of machines have been invented, which make the process continuous. One of these

machines is shown in figure 3. The machine consists of a large tank divided into two compartments and two smaller tanks. These contain water at different temperatures. Bottle-holding frames are carried through these compartments on an endless chain in the manner shown in the drawing. The raw milk is bottled and capped with water-tight caps, then placed on the bottle-holding frames of the machine on the loading end. The bottles of milk are then carried through the preheating compartment into the pasteurizing compartment where they remain for about 30 minutes. From the pasteurizing tank the bottles are carried to the cooling tank, then to the refrigerating tank, after which they are removed from the machine. The process is continuous, the bottles of milk being loaded at one

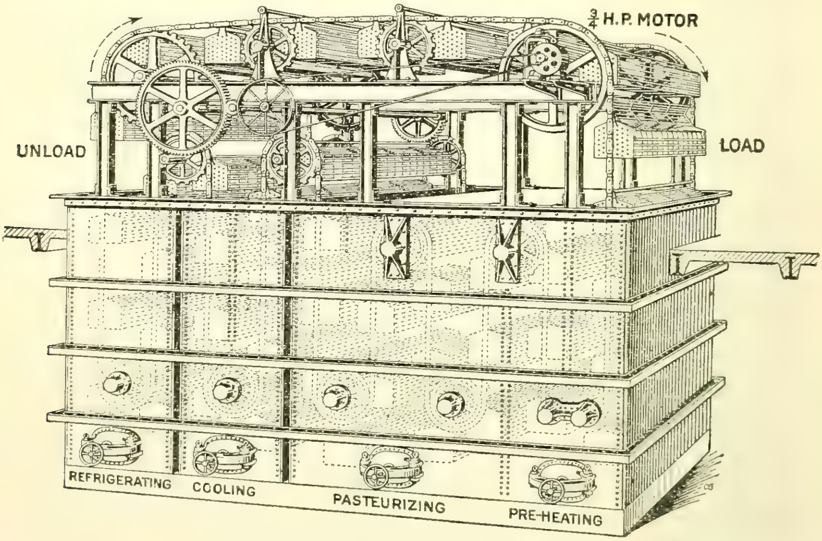

FIG. 3.—Machine for continuous pasteurization of milk in bottles. The bottles have water-tight caps and are conveyed on an endless chain through water compartments of various temperatures.

end, heated, held, and cooled, then unloaded at the other end of the machine. The temperature of the water in this machine is automatically controlled.

There are other machines on the market which differ in the manner in which the bottles are carried through the tanks of water, but the principle is about the same.

In other types of pasteurizers the bottles are not submerged in water and consequently water-tight caps are not necessary. The bottles of milk are heated and cooled by sprays of water and ordinary caps are used and protected from water by a metal covering. One of this type of in-the-bottle pasteurizers is shown in figure 4. The

crates of raw milk are placed on an endless traveling conveyor which passes through the machine and returns under it. The bottom of the machine is divided into several compartments and each compartment is filled with water for supplying the machine when in operation. The top of the machine is a flooding pan divided into compartments corresponding to those in the bottom of the machine. Pumps draw the water from the lower compartments and force it into the corresponding top sections, from which it returns in the form of a shower through perforated bottoms. The process is repeated with the same water. As the crates of milk pass through the machine they pass through showers of water at different temperatures and are heated to the pasteurizing temperature, then held and finally

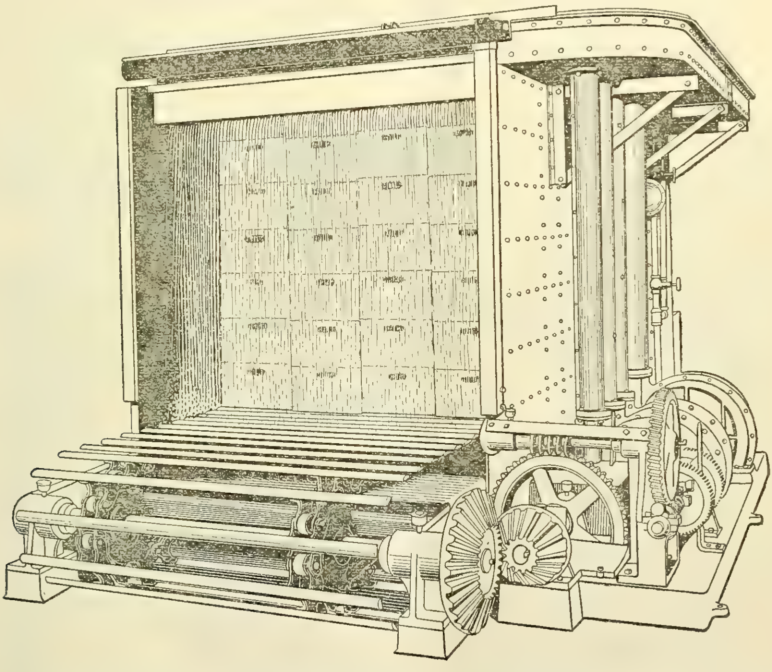

FIG. 4.—Another type of continuous machine in which the bottles of milk have ordinary caps and are passed through showers of water at various temperatures.

cooled. The tops of the bottles are protected from water by metal caps arranged as shown in figure 5. This frame of metal caps covers the top of each bottle in the crate.

The pasteurizing section of the machine is located in the center with the preheating and cooling section at each end. The preheating and cooling sections are connected by channels, because the cool milk entering the machine has a tendency to cool the water and the hot milk emerging from the pasteurizing section has a tendency to heat

it. The temperature of the water in the pasteurizing section is automatically maintained.

In figure 6 is shown another type of in-the-bottle pasteurizer which is so arranged that bottles of milk may be heated with ordinary

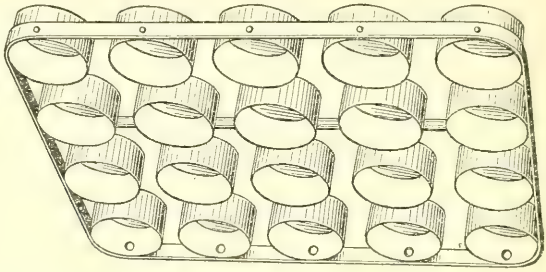

FIG. 5.—Metal caps in frame for protection of bottles as operated in machines shown in figures 4 and 6.

caps. The pasteurizer is made of sheet metal and contains racks which hold crates of bottles. The tops of the bottles are covered with metal caps of the type shown in figure 5. The crates of raw milk covered with metal caps are placed on the racks in the pasteurizer and heated by means of hot water which is forced against the bottles. The water is circulated by means of a pump and is used continuously. After the milk has reached 145° F. it is held for 30 minutes and then cooled. Cooling is accomplished by replacing the

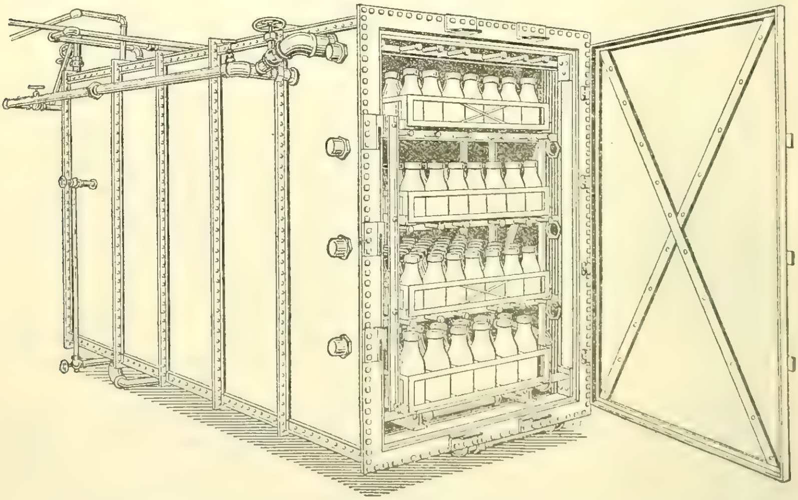

FIG. 6.—A pasteurizing machine in which paper-capped bottles are protected by metal caps, and heating and cooling are done, respectively, by circulation of hot and cold water.

hot water by cold, while for low temperatures a special set of cooling pipes is supplied. The temperature of the heating water can be automatically controlled.

METHOD OF PASTEURIZING MILK IN BULK AND BOTTLING WHILE HOT.

For the pasteurization of milk in bulk a double-walled cylindrical tin tank with a capacity of about 3½ gallons was used. The con-

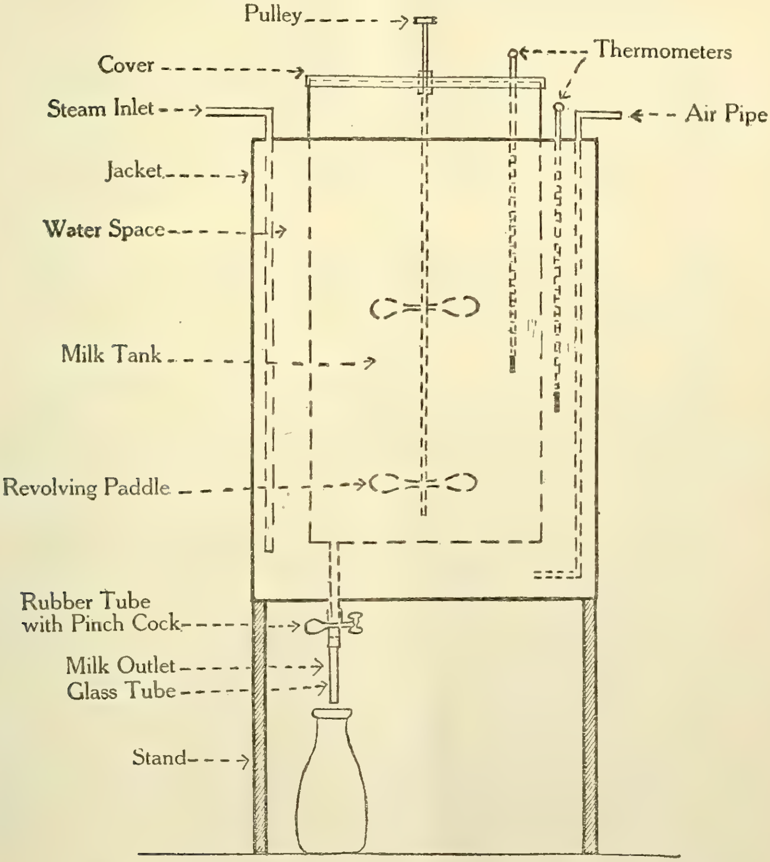

FIG. 7.—Apparatus for pasteurizing milk and bottling while hot.

struction of this tank is shown in figure 7. Raw milk was placed in the milk tank, where it was heated by hot water in the outer jacket. The surrounding water was heated by a steam jet and constantly agitated by blowing in a small amount of air. During the heating the milk was agitated by a paddle supported by the cover of the milk tank. The water in the jacket was kept at a temperature of about 146° F. The milk was held at a temperature of 145° F.

for 30 minutes and then drawn off while hot through the outlet pipe into hot milk bottles which had been steamed 2 minutes. As stated before, this method of bottling milk while hot was suggested in Circular 184 of the Bureau of Animal Industry (5), but the suggestion then was to bottle hot milk in cold bottles. In this work it seemed advisable to bottle directly into hot bottles, as it makes it possible to steam the bottles and fill them before infection can take place. Also, this method eliminates the possibility of breaking bottles. While working on this process of bottling milk hot it has been found that a similar process was apparently patented several years ago, but, so far as known, it has never been used to any extent. This process as described by de Schweinitz (7) consisted in pasteurizing the milk at temperatures from 160° to 180° F. and placing it while hot in a sterilized milk jar or fruit jar with a flap top. Special paper caps were used. The jars of milk were cooled by being placed in troughs of iced water.

COMPARISON OF BACTERIAL REDUCTIONS IN MILK PASTEURIZED IN BOTTLES AND MILK PASTEURIZED IN BULK AND BOTTLED WHILE HOT.

Since it has been shown earlier in this bulletin that excellent bacterial reductions may be obtained by pasteurization in bottles, a question of great importance arises as to whether or not as good results can be obtained by pasteurizing milk in bulk and bottling while hot.

A series of 22 samples of raw milk was pasteurized by both processes at 145° F. for 30 minutes. Part of the milk was pasteurized in bulk in the pasteurizer shown in fig. 7 and bottled hot in hot bottles which had been previously steamed for two minutes. In all these experiments the bottles were capped with ordinary paper caps, no precautions being used in capping by hand. Another portion of the same raw milk was pasteurized in bottles. Both samples of pasteurized milk were examined bacteriologically while hot in the bottles.

In the first series the bottles in which the milk was pasteurized directly were washed with hot water and washing powder immediately before they were filled with raw milk.

TABLE 2.—*Comparison of bacterial reductions in milk pasteurized in unsteamed bottles and in pasteurized milk bottled while hot in steamed bottles.*

Sample No.	Raw milk (bacteria per c. c.).	Milk pasteurized at 145° F. for 30 minutes.			
		Hot pasteurized milk in hot steamed bottles.		Milk pasteurized in washed but unsteamed bottles.[1]	
		Bacteria per c. c.	Percentage reduction.	Bacteria per c. c.	Percentage reduction.
2	58,000	1,160	98.00	1,630	97.18
3	63,000	220	99.65	1,070	98.30
4	5,100,000	8,400	99.83	11,800	99.76
5	580,000	8,300	98.57	8,000	98.62
6	5,900,000	6,000	99.90	15,600	99.74
7	99,000	610	99.38	980	99.01
8	7,400,000	6,300	99.91	7,100	99.90
9	191,000	2,000	98.95	7,600	96.02
10	14,100,000	7,000	99.95	14,200	99.89
11	24,700	4,550	81.58	5,780	75.59
12	75,000	3,000	96.00	28,000	62.66
13	126,000	1,440	98.86	1,720	98.63
14	4,100,000	2,470	99.94	2,410	99.94
15	76,000	1,400	98.16	3,550	95.32
16	8,100,000	1,620	99.98	1,660	99.98
17	18,900	760	95.97	710	96.24
18	24,000	800	96.66	10,900	50.41
19	28,300	7,050	75.09	23,300	17.67
20	80,000	1,360	98.30	2,010	97.48
21	160,000	1,830	98.86	29,500	81.56
22	151,000	3,200	97.88	12,500	91.72
23	81,000	6,800	91.60	9,800	87.90
Average	2,115,268	3,467	96.50	9,083	88.34

[1] Bottles were washed clean in hot water, but not steamed, before they were filled with raw milk.

The results of the bacteriological examinations are shown in Table 2. It will be seen that the average count of the raw milk was 2,115,268 bacteria per cubic centimeter. After being pasteurized in bulk and bottled hot in hot steamed bottles the average count was 3,467 bacteria per cubic centimeter, while the average count when pasteurized in bottles was 9,083 bacteria per cubic centimeter. Comparing the percentage of bacterial reductions, it will be noted that the average reduction of the milk bottled hot was 96.50 per cent and only 88.34 per cent in the milk pasteurized in bottles. In 19 of the 22 samples the bacterial count was lower in milk pasteurized in bulk and bottled hot. In many cases the count was much lower, as may be seen by comparing samples 4, 6, 7, 12, and 18. This difference is particularly striking in sample 21, in which milk pasteurized in bulk and bottled hot showed a count of 1,830, and some of the same milk pasteurized in a bottle for the same time and at the same temperature contained 29,500 bacteria per cubic centimeter.

In the belief that this marked difference might be due to the fact that the bottles were steamed in the first case and unsteamed when the milk was pasteurized directly in bottles, another series of samples was pasteurized in which both bottles were steamed for two minutes

in order to eliminate this factor of possible infection. The result of these experiments are shown in Table 3.

TABLE 3.—*Comparison of bacterial reductions in milk pasteurized in steamed bottles and in pasteurized milk bottled while hot.*

Sample No.	Raw milk.	Milk pasteurized at 145° F. for 30 minutes.			
		Hot pasteurized milk in hot steamed bottles.		Milk pasteurized in steamed bottles.[1]	
	Bacteria per c.c.	Bacteria per c.c.	Percentage reduction.	Bacteria per c.c.	Percentage reduction.
24	24,900	380	98.47	570	97.71
25	94,000	860	99.08	2,200	97.66
26	305,000	21,800	92.85	55,800	81.70
27	235,000	5,400	97.70	7,600	96.76
28	176,000	2,200	98.75	11,400	93.52
29	97,000	5,900	93.91	8,350	91.39
30	230,000	6,300	97.26	5,500	97.61
31	124,000	920	99.26	1,500	98.79
32	450,000	4,200	97.47	11,400	97.46
33	3,950,000	4,320	99.89	3,520	99.91
34	985,000	11,800	98.80	18,400	98.13
35	190,000	7,500	96.06	9,300	95.10
Average	571,766	5,965	97.46	11,295	95.48

[1] Bottles were steamed two minutes, and cooled before they were filled with raw milk.

It will be seen that the results again were in favor of the milk pasteurized in bulk and bottled while hot. Of the 12 samples in the experiment 10 showed lower counts than when the milk was pasteurized in the bottles.

The average count of the raw milk was 571,766 bacteria per cubic centimeter. After pasteurization in bulk, followed by bottling hot, the count was 5,965, and a portion of the same milk pasteurized in bottles averaged 11,295 bacteria per cubic centimeter. In several of the samples the count in the milk pasteurized in bottles was very much higher than in the same milk pasteurized in bulk and bottled hot. The explanation of these marked differences is not known. While minor differences are always within the limits of the errors of bacteriological methods, the great differences found in many cases can not be explained in this manner.

PREVENTION OF BOTTLE INFECTION BY BOTTLING HOT MILK AND BY PASTEURIZATION IN BOTTLES.

Since the process of pasteurizing milk in bulk and bottling while hot enables the use of hot, steamed bottles which can be directly filled with hot milk, it should be expected that there would be no contamination added to the milk during bottling.

To determine this point eight samples of milk were pasteurized in bulk and bottled hot in hot, steamed bottles. The bacteriological results are shown in Table 4, column A. Two steamed and cooled

milk bottles for each sample were inoculated with equal amounts of sour milk. One of these infected bottles was then steamed for two minutes and filled with hot pasteurized milk and the other contaminated bottle not heated was filled with some of the same pasteurized milk, which had been previously cooled in a sterile bottle. An examination of Table 4 shows, when the figures in columns A and C are compared, that the infectious material added to the bottle was entirely destroyed by the method of bottling, at least so far as bacteriological methods can detect, since any marked increase in column C would show infection. Column B shows the bacterial counts obtained by putting cold pasteurized milk into infected bottles. From these results it is evident that the process of bottling hot pasteurized milk in hot, steamed (two minutes) bottles entirely eliminates the factor of bottle infection, which may often be serious in the ordinary processes of pasteurization on a commercial scale.

TABLE 4.—*Destruction of bottle infection during the process of bottling hot pasteurized milk.*

Sample No.	Raw milk.	Hot pasteurized milk in hot steamed bottles.	Cold pasteurized milk in cold infected bottles.[1]	Hot pasteurized milk in steamed infected bottles.[1]
		A	B	C
	Bacteria per c. c.	*Bacteria per c. c.*	*Bacteria per c. c.*	*Bacteria per c. c.*
24	24,900	380	6,400,000	460
25	94,000	860	5,600,000	600
27 [2]	235,000	5,400	1,330,000	4,800
28	176,000	2,200	1,510,000	2,400
29 [2]	97,000	5,900	235,000	4,100
30 [2]	230,000	6,300	355,000	5,800
31 [2]	124,000	920	305,000	950
35 [2]	190,000	7,500	....	8,800

[1] Bottles had been previously infected with several cubic centimeters of sour milk.
[2] Bottle infected with old, sour, pasteurized milk.

The question naturally arose as to whether or not pasteurization in bottles would destroy infection in bottles specially infected before being filled with raw milk. To determine this point nine samples of milk were pasteurized which had been previously steamed and cooled. The results are shown in Table 5. One bottle for each sample was steamed, cooled, infected with several cubic centimeters of sour milk, and filled with some of the original raw milk. Samples were then plated from this bottle to show the extent of the infection, the results of which may be found in column B of the table. The bottle of infected raw milk was capped with a seal cap and the milk pasteurized directly in the bottle. Plates were made directly after the heating and the bacteriological results are shown in column C. Any increase in the counts in column C over those in column A shows

the amount of infection introduced by placing milk in an infected bottle. It is evident that in only two samples, Nos. 28 and 35, was the infection entirely destroyed.

TABLE 5.—*Destruction of bottle infection during the process of pasteurization in bottles.*

Sample No.	Raw milk.	Milk pasteurized in clean previously steamed bottles. A	Bottles infected with sour milk and filled with raw milk. B	Milk pasteurized in infected bottles. C
	Bacteria per c. c.	*Bacteria per c. c.*	*Bacteria per c. c.*	*Bacteria per c. c.*
24	24,900	570	3,700,000	2,090
25	94,000	2,200	3,300,000	6,200
27[1]	235,000	7,600	760,000	9,500
28	176,000	11,400	650,000	11,000
29[1]	97,000	8,350	530,000	20,000
30[1]	230,000	5,500	645,000	20,900
31[1]	124,000	1,500	400,000	28,600
35[1]	190,000	9,300	230,000	9,600
36[1]	38,000	5,600	92,000	17,700

[1] Bottle infected with old, sour, pasteurized milk.

It is quite possible that infection from unclean bottles might become a serious factor in bottle pasteurization. When one considers that in pasteurization in the bottle the bacteria which are left are either heat-resistant vegetative cells or spores, it is easy to see that if a large number are left in a bottle and it is again filled with milk and pasteurization again performed in the bottle these same bacteria will again survive and increase the number left. It is advisable to steam the bottles at least two minutes before filling with milk for pasteurization in the bottles.

COOLING MILK WHICH HAS BEEN BOTTLED HOT.

When a water-tight cap is used it is, of course, possible to bottle the milk while hot and cool by submerging in cold water, but experiments have been made with a process by which the milk may be cooled in bottles capped with ordinary cardboard caps. Briefly stated, the process consists in exposing the hot bottled milk to an air blast. The air-blast system is used at present in the hardening rooms in ice-cream plants, but, so far as known, this system has never been applied to the cooling of milk.

Several experiments were tried on a laboratory scale which gave promising results. When a bottle of hot milk is allowed to cool in still air a film of warm air forms about it which can move away only by convection, and, naturally, the cooling process is slow. If some means were provided for moving the film of warm air and forcing

cool air against the bottle, heat would constantly be given up with more rapidity by the milk and the cooling process hastened. In figure 8 are shown the temperatures in three bottles of milk cooled for 30 minutes in air. One bottle was cooled in still air at 77° F., one was cooled in an air blast from an electric fan at a temperature of 77° F., and one was cooled in still air at 35° F. At the beginning of the cooling the temperature of the milk was about 145° F. As will be seen from the curves, after 30 minutes' cooling the temperature of the milk in the bottle cooled in still air at 77° F. was about 127.5° F., while that of the milk cooled in an air blast at 77° F. was about 102° F. It is noted that by cooling in an air blast for 30 minutes

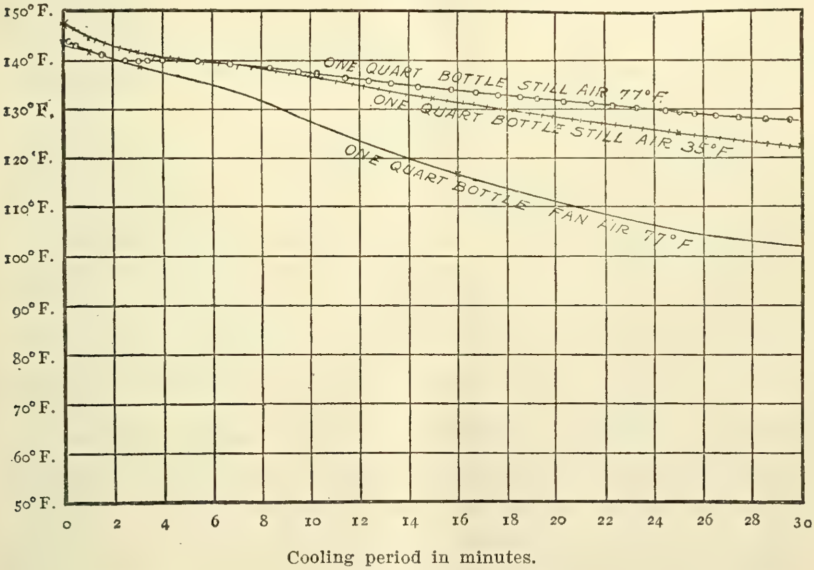

FIG. 8.—Effect of cooling a quart bottle of milk in still air and in an air blast.

there was a reduction in temperature of about 25.5° F. in excess of that obtained under the same conditions in still air. The temperature curve of the milk in the bottle cooled in still air at 35° F. follows closely that of the milk cooled in still air at 77° F. It is also interesting to note that after cooling for 30 minutes in still air at 35° F. the temperature was 122° F., while that of the milk cooled in an air blast at 77° F. was about 102° F., a difference of 20° F.

Since these experiments indicated that hot bottled milk might be cooled more rapidly by using a blast of cold air, another experiment was conducted in which one quart and one pint bottle were cooled in still air which averaged 39.4° F. and another set in an air blast the temperature of which averaged 44.3° F. The blast of cold air was obtained by placing an electric fan in a refrigerator. The fan de-

livered air at a velocity of about 1,250 feet per minute. The temperature curves in figure 9 show the results of this experiment. The temperatures of the hot milk at the beginning of the cooling ranged from 140° to about 143.5° F. in the different bottles. It will be seen from the curves that five and one-half hours were required for the temperature of the quart bottle of milk in still air to reach 50° F., while the milk in a quart bottle in an air blast was cooled to 50° F. in a little over two hours. The milk in the pint bottle cooled in still air reached a temperature of 50° F. after about three and one-half hours, while only one and one-half hours were required to cool the milk in the pint bottle which was in a blast of cold air.

From these results there can be no doubt as to the value of an air blast for cooling bottles of hot milk, at least as compared with still air as a cooling medium. As these experiments were made on single

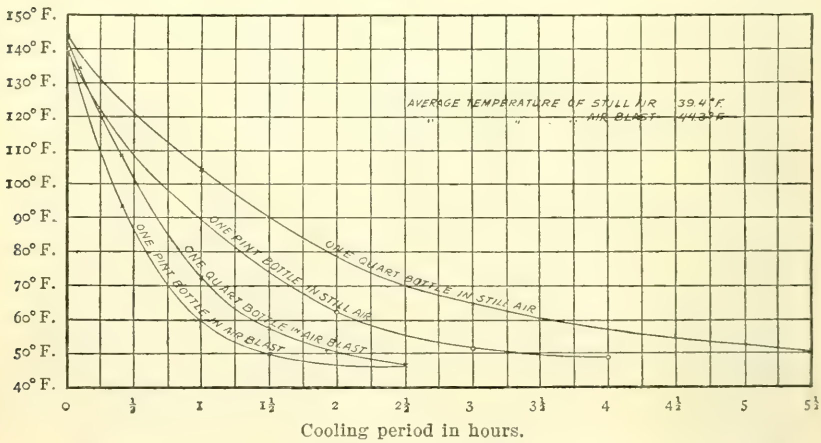

FIG. 9.—The cooling of pint and quart bottles of hot milk in still air and in an air blast at refrigerator temperature.

bottles it was thought advisable to try cooling several crates of bottled hot milk by an air blast. Specially constructed skeleton-frame steel crates were used, so as to allow a free circulation of air.[1] Milk was pasteurized at 145° F. for 30 minutes and bottled hot in ordinary milk bottles by the aid of a hand bottle filler. The bottles were then capped with the ordinary cardboard caps and placed in crates. Four crates were used in these experiments, two filled with quart and two with pint bottles. The two crates which contained quart bottles were placed in a refrigerator room one above the other, and directly back of them were placed the two crates of pint bottles one above the other. The air blast was generated by a 16-inch desk

[1] Mr. John T. Bowen, of this division, assisted in this work.

fan, which gave an air velocity of about 1,250 feet per minute. The fan was placed about 2½ feet in front of the pile of four crates directly facing the crates with quart bottles. Temperatures were taken in two quart bottles, one in the front and the other in the back row. In this experiment the crates were cooled in a refrigerator room, the temperature of which varied from 40° to 44° F. The results of this experiment are shown in figure 10, together with the results of a similar experiment in which the crates were cooled in an air blast at a temperature of about 76° F. for a period of 2¼ hours. The crates were then placed in a refrigerator and the cooling continued, a blast of air with a temperature of about 41° F. being used. The curves in figure 10 show the averaged temperatures of two quart

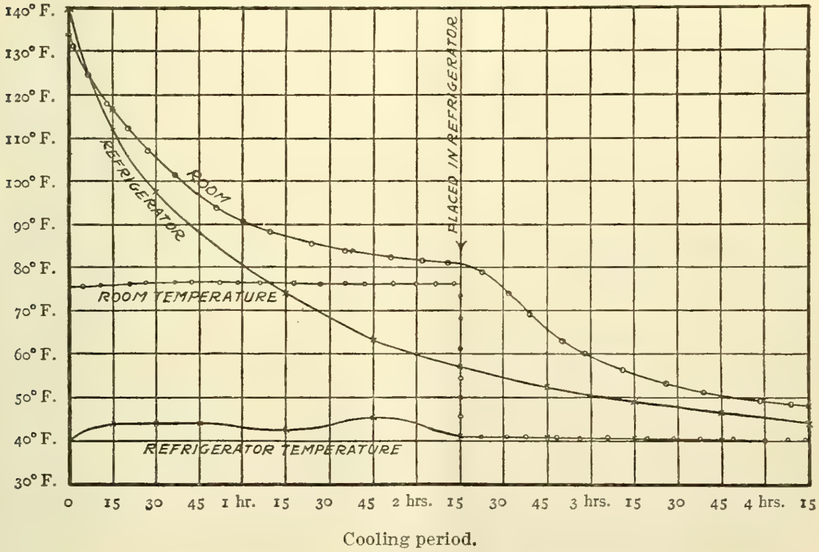

FIG. 10.—Effect of cooling crates of bottled hot milk in an air blast at different temperatures.

bottles. It will be seen from curve A that about 3 hours and 7 minutes were required to cool the milk in quart bottles from 140° to 50° F. when cooled in a blast of cold air during the entire period. A comparison of curves A and B shows that it took only about 45 minutes longer to cool to 50° F. the milk in bottles exposed to an air blast at room temperature for the first 2¼ hours. It is interesting to note that curves A and B follow each other fairly closely during the first 30 minutes of cooling. These results suggest that the cooling of hot pasteurized bottled milk may be accomplished by cooling with an air blast at ordinary room temperature and completed by cooling in a blast of cold air in a refrigerator room. The greater the number of

heat units which can be removed from the milk by an air blast at room temperature the cheaper the cost of cooling, since refrigeration would be saved and about the only cost would be the operation of a blower.

These experiments, although by no means conclusive as to the value of this method of cooling by an air blast on a practical scale, since many complications may arise in the practical application, indicate great possibilities for such a system.

THE EFFECT OF QUICK AND SLOW COOLING ON THE BACTERIAL FLORA OF THE MILK.

It is believed that any system of pasteurization in which the milk is not cooled immediately after heating will be looked upon with suspicion and will excite comment. It has always been supposed that immediate cooling was an indispensable part of the process of pasteurization, first, because sudden changes in temperature were believed to have a destructive effect on the bacterial cells, and second, because it has been supposed that bacteria left after pasteurization would immediately begin to grow unless the milk was cooled at once.

As stated earlier in this bulletin, it was shown in Bulletin 161 (3) that sudden cooling played no part in the destruction of bacteria. There remains, therefore, one question to be answered, How quickly must pasteurized milk be cooled in order to check bacterial growth?

From the writers' former studies of pasteurization it seemed apparent that the bacteria which survived heating were somewhat weakened or at least did not begin to grow as might theoretically be expected. These observations naturally gave rise to the idea that pasteurized milk might be cooled directly in bottles by a cold air blast, provided the cooling period did not extend over a few hours.

In order to obtain data on this question 10 samples of milk were pasteurized and bottled hot in steamed bottles. Two bottles for each sample were cooled as follows: One bottle was cooled within half an hour in ice water and placed in a refrigerator at 45° F. for 17½ hours; the other bottle was cooled slowly at room temperature for 4 hours and placed in a refrigerator at 45° F. for 14 hours. At the end of that time each bottle of milk was 18 hours old; one was cooled quickly and had been at 45° for 17½ hours; the other had been cooled slowly and had been at 45° for probably a very short time, because, although it had been in the refrigerator for 14 hours, the milk was warm when placed there, and cooling in still air is a slow process. Both bottles after the 18-hour cooling period were allowed to stand at temperatures of from 75° to 86° F. for a period of 6 hours. The bacterial results are shown in Table 6.

TABLE 6.—*Number of bacteria per cubic centimeter in pasteurized milk bottled hot, cooled quickly and slowly, and subsequently held at room temperature.*

Method of cooling.	Sample No.										Average of 10 samples.
	1	2	3	4	5	6	7	8	9	10	
Bacteria in the raw milk	95,000	176,000	176,000	97,500	97,500	......	450,000	......	985,000	38,000	264,375
Bottle No. 1, cooled quickly:											
Directly after pasteurization	600	1,870	1,570	5,900	5,900	22,900	890	4,800	8,300	5,500	5,823
After one-half hour in ice water and 17½ hours at 45° F	1,000	[1] 2,050	[1] 2,370	......	......	16,600	1,700	2,500	8,900	5,200	5,040
After 6 hours at 86° F	......	5,750	8,400	6,600	5,900	......	......	......	[2] 9,600	[2] 5,200	6,908
Bottle No. 2, cooled slowly:											
Directly after pasteurization	860	1,320	1,220	5,900	5,900	21,800	890	5,400	7,500	6,500	5,729
After 4 hours at room temperature and 14 hours at 45° F	500	1,180	5,520	......	......	12,300	2,200	715	9,800	5,200	4,678
After 6 hours at 86° F	......	5,800	6,100	3,700	3,700	......	......	......	[2] 8,900	[2] 5,300	5,583

[1] Held at 45° F. for 21 hours in place of 18 hours. [2] Held at 75° F. instead of 86° F.

As may be seen from Table 6, bacterial counts were made of the raw milk on each bottle directly after pasteurization, at the end of the 18-hour cooling period, and again after the milk had been at room temperature for six hours. The bacterial results obtained showed that there was no more increase in the pasteurized milk cooled slowly than in similar milk cooled within half an hour and held at low temperatures for 18 hours. Neither was there any difference in the bacterial numbers even after milk cooled by both processes had been removed, after 18 hours' cooling, and allowed to stand for six hours. The various counts from 10 samples have been averaged and are given in the last column in order to show more plainly the effect of the two systems of cooling on the bacterial numbers in milk. It will be seen that the average bacterial counts of the milk cooled slowly are even lower than those of milk cooled quickly. While this difference is probably an experimental error, it is evident that bacterial growth in the pasteurized milk was not increased by the slow-cooling process.

The writers do not wish to convey the idea that pasteurized milk need not be cooled at all. The cooling of any milk is absolutely essential in order to restrain bacterial growth, and the fact should be emphasized that the process of cooling pasteurized milk slowly does not dismiss the cooling process but simply makes use of a slower cooling process than is in use at present.

In order to show, respectively, the effect on the bacterial content of cooling quickly, cooling slowly, and not cooling to low temperatures at all, three experiments were made. Milk was pasteurized in bulk and three steamed and hot quart bottles were filled with the hot milk. One bottle was cooled in iced water in half an hour to 50° F. and refrigerated at 45° F. Another bottle was cooled in a blast of air at room temperature for half an hour during which time the

temperature dropped from 145° to about 100° F. The milk was then allowed to stand at a temperature of from 100° to 80° F. for five hours, after which it was placed in a refrigerator at 45° F., where it cooled slowly in still air. The remaining bottle was cooled for half an hour in an air blast at room temperature and allowed to remain at a temperature of about 75° F. through the entire experiment. The results of these experiments are given in Table 7.

TABLE 7.—*Effect of different methods of cooling on the bacterial content of pasteurized milk.*

Method of cooling.	Sample No.		
	1	2	3
	Bacteria per c.c.	*Bacteria per c.c.*	*Bacteria per c.c.*
Raw milk	9,050,000		11,900,000
Bottle No. 1, cooled quickly:			
Directly after pasteurization	6,450	2,110	8,500
Held at 45° F. for 22 hours	5,050	1,720	28,400
Held at 75° F. for 6 hours	4,800	2,340	76,500
Held at 75° F. for 24 hours	1,370,000	885,000	
Bottle No. 2, cooled slowly:			
Directly after pasteurization	7,150	2,580	11,900
Held at 75° F. for 5 hours	6,100	1,600	29,000
Held at 45° F. for 17 hours	6,200	2,400	192,000
Held at 75° F. for 6 hours	9,600	2,740	348,000
Held at 75° F. for 24 hours	2,760,000	850,000	
Bottle No. 3, cooled at room temperature:			
Directly after pasteurization	4,950	2,180	8,500
Held at 75° F. for 5 hours	6,850	2,890	25,000
Held at 75° F. for 22 hours	700,000	2,420,000	83,400,000
Held at 75° F. for 28 hours	2,750,000	13,400,000	269,000,000
Held at 75° F. for total of 66 hours	460,800,000		

A study of the table shows that there was no increased bacterial growth with samples 1 and 2 caused by holding the pasteurized milk for five hours after bottling hot, even though the temperature during that period ranged from 100° to 80° F., which is the most favorable temperature for bacterial development. With sample 3 there was an increased growth over that in the milk cooled quickly. It must be remembered that these experiments represent extreme conditions in slow cooling, but the fact is apparent that the cooling process should not extend over five hours. The effect of not cooling milk to low temperatures is plainly shown in the table by a comparison of the bacterial counts with those of milk cooled both quickly and slowly. It is believed from these experiments that it is possible to cool hot bottled pasteurized milk by a blast at room temperature followed by a blast of cold air without any more bacterial development than would take place if the milk were immediately cooled, provided the milk is cooled to 50° F. gradually within five hours. This is not made as a definite statement, because different results may, of course, be obtained when milk is thus cooled on a commercial scale.

Again let the fact be emphasized that pasteurized milk or raw milk must be kept at low temperatures after cooling in order to check bacterial development.

THE CREAM LINE AND FLAVOR OF PASTEURIZED MILK COOLED BY VARIOUS METHODS.

In the consideration of the process of bottling hot pasteurized milk followed by slow cooling it is of practical importance to know what effect such a process will have on the cream line and flavor of the milk. Several experiments were made to determine the effect on these points. Milk was pasteurized, and hot 500-cubic-centimeter graduated cylinders were filled with hot milk up to the 500-cubic-centimeter mark. Together with the cylinder of hot pasteurized milk one cylinder was filled with raw milk and one with pasteurized milk which had been cooled to 50° F. in 15 seconds' time by running through a coil immersed in brine. The method of cooling the hot cylinders of pasteurized milk was varied considerably, as may be seen from Table 8. After holding the milk for 24 hours at 45° F. the numbers of cubic centimeters of cream were read off directly from the graduations on the cylinder. This method, of course, gave a very accurate means of determining the effect of heating and cooling on the cream line; in fact it was too accurate, since considerable differences in the cream line by this method of measurement were not apparent in bottled milk.

TABLE 8.—*Cream-line experiments with raw milk and milk pasteurized at 145° F. for 30 minutes.*

Experiment No.	Process.	Cubic centimeters of cream in 500 c. c. cylinder after 24 hours' refrigeration at 45° F.
1	Raw milk	64.5
	Pasteurized milk:	
	Cooled quickly in 15 seconds to 50° F. and held in refrigerator at 45° F.	64.5
	Cooled slowly in air blast for 45 minutes and placed in refrigerator at 45° F.	65.0
	Held above 105° F. for 3 hours, cooled in ice water, and placed in refrigerator at 45° F.	64.5
2	Raw milk	65.0
	Pasteurized milk:	
	Cooled in 15 seconds to 50° F. and placed in refrigerator at 45° F.	62.5
	Cooled slowly in air blast for 1½ hours and placed in refrigerator at 45° F.	52.5
	Held above 100° F. for 1½ hours and placed in refrigerator at 45° F.	52.5
3	Raw milk lost	....
	Pasteurized milk:	
	Cooled in 15 seconds to 50° F. and placed in refrigerator at 45° F.	83
	Cooled slowly for 30 minutes in air blast, cooled quickly in brine, and placed in refrigerator at 45° F.	85
	Held above 100° F. for 3 hours, cooled quickly in brine, and placed in refrigerator at 45° F.	90
4	Raw milk lost	....
	Pasteurized milk:	
	Cooled in 15 seconds to 50° F. and placed in refrigerator at 45° F.	75
	Cooled slowly in air blast for 2½ hours, cooled in ice water, and placed in refrigerator at 45° F.	69
	Held above 100° F. for 2½ hours, cooled in ice water, and placed in refrigerator at 45° F.	75
5	Raw milk	80
	Pasteurized milk:	
	Cooled in 15 seconds to 50° F. and placed in refrigerator at 45° F.	68
	Cooled slowly in air blast for 2 hours and placed in refrigerator at 45° F.	55
	After cooling in air blast for 2 hours the milk was cooled quickly in brine to 50° F. and placed in refrigerator at 45° F.	62
	Held above 100° F. for 5 hours and placed in refrigerator at 45° F.	55
	After holding above 100° F. for 5 hours the milk was cooled quickly in brine to 50° F. and placed in refrigerator at 45° F.	62

A study of the results in Table 8 shows that the cream-line formation is a variable factor. Sometimes it was reduced by pasteurization even when the milk was cooled to low temperatures within 15 seconds, and at other times there was no difference. In some experiments the cream line was slightly less on milk cooled slowly and again it was slightly higher. Throughout the experiments on pasteurized milk bottled hot in ordinary milk bottles a good clear cream line was obtained. When milk stood at temperatures above 80° F. for several hours without agitation some of the melted butter fat rose to the top of the bottle and on cooling formed a small lump of butter. This was not observed, however, when the cooling process was begun immediately after bottling, even though the cooling was gradual.

As to the effect on the flavor of the milk, it may be said that there was no more effect than that produced by milk pasteurized and cooled rapidly, except in instances where the milk was held above 100° F. for several hours, as was the case in some of the experiments, in which a slightly more pronounced cooked taste was noticeable in the milk.

In this connection attention is called to the fact that these results hold only for milk pasteurized at 145° F. and can not be applied where higher temperatures might be used, as it is possible that with higher temperatures different results might be obtained.

BOTTLES TO BE USED IN THE PROCESS OF BOTTLING HOT PASTEURIZED MILK.

It is obvious that a quart bottle filled with milk at 145° F. will not contain a full quart when the milk has cooled to 50° F., owing to the contraction during cooling. Several experiments which were made to determine the loss in volume during cooling showed a shrinkage in a quart bottle which averaged about 18.40 cubic centimeters. Assuming a quart of milk to be 946.35 cubic centimeters, that volume at 145° F. would therefore contract to about 927.95 cubic centimeters when cooled to 50° F. If a quart bottle is filled with milk at 145° F., it will be 18.40 cubic centimeters, or 0.62 of an ounce, short of 1 quart when cooled to 50° F. To overcome this shortage bottles of a slightly larger capacity should be used when filled with milk at 145° F. A bottle should be of sufficient size to hold 1 quart of milk measured at 50° F. which has been heated to 145° F.

PROCESS OF BOTTLING HOT PASTEURIZED MILK UNDER COMMERCIAL CONDITIONS.

Having discussed the various steps in the process of bottling hot pasteurized milk, the possible application of this process of commercial conditions may be outlined.

Milk can be pasteurized by the ordinary holder system at 145° F. for 30 minutes. It can then be bottled hot in special oversized milk bottles of the ordinary type and capped with ordinary sterile caps. Before being filled the bottles can be steamed for two minutes by running the crates inverted on a conveyer over steam jets. The bottles would then go through the bottling machine in a hot condition and would be practically sterile. The crates of hot bottled pasteurized milk can then be cooled by stacking in a refrigerator room and blowing cold air through the crates. In the cold season outside air can be used for cooling, and in the warm season refrigerated air can be circulated through the crates.

This process can be modified. The hot milk can be held in the bottles at 145° F. instead of in a tank, and the crates of hot pasteurized milk can be cooled by spraying with cold water instead of air.

From the results of experiments with air cooling on a small practical scale started in 1913, it is believed to be entirely practical to cool hot bottled milk by means of forced-air draft. The results of this work are being prepared for publication in the near future.

Since the process of bottling hot pasteurized milk has not as yet been worked out for practical use, it is impossible to state definitely all its advantages and disadvantages. However, from laboratory experiments alone certain advantages are plainly shown. From a sanitary standpoint one great advantage of the process of bottling hot pasteurized milk in hot bottles lies in the fact that bottle infection is eliminated. From a commercial standpoint there is also an advantage, because of the reduction of milk losses on the cooler caused by adherence of milk and by evaporation. Ordinary cardboard caps may be used in this system, since they do not have to be water-tight, which is obviously a point of great advantage so far as cost is concerned.

At the present stage of this work it is impossible to state how the cost of air cooling will compare with the ordinary methods in practice, but it is believed that there will be no more expense involved.

The length of time required for cooling is perhaps the greatest disadvantage of this process, and yet this would be of no consequence except in plants where the milk is delivered immediately after pasteurization. In the majority of milk plants the milk is pasteurized in the morning or afternoon, placed in refrigerators, and delivered early the next morning. Consequently in most plants it would make little difference whether the cooling process was performed quickly or slowly.

SUMMARY.

1. The process of pasteurization in the bottle, using a temperature of 145° F. for 30 minutes, causes satisfactory bacterial reductions.

2. Bottles should be steamed at least two minutes before being filled with milk in order to destroy heat-resistant types of organisms which might survive the pasteurizing temperature and thereby increase the bacterial count.

3. Care must be taken to record the temperature in the bottom of the bottle during the heating process. When milk at an initial temperature of 50° F. is heated in bottles without agitation in water at about 146° F. the temperature of the milk in the top of the bottle will reach 140° F. about nine minutes before that in the bottom. The temperature of the milk during the process of pasteurizing in the bottle should be recorded by placing a thermometer in a control bottle with the bulb of the thermometer about one-half inch from the bottom. The milk should be heated for 30 minutes at 145° F.

4. When bottles are heated and cooled under water care should be taken not to use bottles with chipped or otherwise imperfect tops, since the seal caps may allow leaks during the process of pasteurizing. It is advisable for the users of patented seal caps to assure themselves that the caps are water-tight, since leaking caps may cause dangerous infections, particularly if the cooling water is polluted.

5. The process of bottling pasteurized milk while hot in hot steamed bottles causes equally good bacterial reductions as does pasteurization in bottles. Even with the same length of exposure of 30 minutes and the same temperature of 145° F. the bacterial reductions are often much greater than those produced by pasteurization in bottles.

6. In the process of bottling hot, bottle infection is eliminated, even when several cubic centimeters of old, sour milk are added to bottles before filling. The two-minute steaming period to which the bottles are subjected before filling with hot milk is sufficient to destroy the contamination, at least so far as bacteriological methods can detect.

7. Laboratory experiments indicate that milk may be pasteurized, bottled hot, capped with ordinary cardboard caps, and cooled by a blast of cold air.

8. It is probable that if milk is cooled from 145° to 50° F. within five hours no more bacterial increase will take place during the slow cooling than would take place if the milk were cooled immediately to 50° F. Whether or not this will be true under commercial conditions can be determined only by future experiments.

9. So far as the laboratory experiments indicate, when milk is heated to 145° F. for 30 minutes, the bottling of the hot pasteurized milk followed by slow, gradual cooling has no more appreciable

effect on the cream line or flavor of milk than the ordinary process of pasteurization. This is true of cooling periods of less than five hours' duration.

10. Since milk contracts on cooling, a quart bottle filled with milk at 145° F. does not hold a full quart when the milk is cooled to 50° F. It is about 0.62 of an ounce short. Therefore slightly oversized bottles should be used.

11. The advantage of the process from the commercial standpoint are: (1) That bottle infection can be eliminated; (2) that milk losses are saved, owing to evaporation over the cooler; and (3) that ordinary cardboard caps can be used. The principal disadvantage is that the air-cooling process requires several hours. This, however, would be a disadvantage only in the few plants where milk is delivered directly after pasteurization.

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 241

Contribution from the Bureau of Chemistry, Carl L. Alsberg, Chief.
June 14, 1915.

STUDIES ON FRUIT JUICES.

By H. C. Gore,
Chemist in Charge, Fruit and Vegetable Utilization Laboratory.

INTRODUCTION.

The studies described in this bulletin were made with a view of finding methods for the preparation of juices from such fruits as the strawberry, blackberry, pineapple, orange, and lemon, which are less well known as sources of juice than the grape and apple. The work was directed toward the preparation of juices of well known varieties of fruit likely to be produced in quantities which would leave a surplus beyond the market demand for them as fresh fruit. The actual fruit used wherever practicable was that produced under typical conditions in localities where it is grown extensively. While final determination of the value of all the methods has not been made, the results of the studies are published in the belief that they will be useful to those giving attention to this neglected field of fruit conservation, and in the hope that they may stimulate others to develop methods which will make much fruit that is now wasted of commercial value to growers and a source of food to the people. The work was taken up at the suggestion of Mr. W. A. Taylor, of the Bureau of Plant Industry, and has been continued during the past four years in cooperation with him and with Mr. A. V. Stubenrauch, formerly of that bureau. The variety of fruit and the locality were selected by Mr. Taylor or Mr. Stubenrauch.

The experiments developed the fact that ordinary methods of sterilizing fruit juices by heat could be successfully applied to but a limited number of the special fruits such as the black raspberry, blackberry, black currant, sour cherry, and peach. In the case of the juices of the strawberry, red raspberry, red currant, pineapple, and the citrus fruits, as well as apple cider, sterilization by heat caused loss in flavor, and where kept after heat sterilization the juices of these fruits tended to lose color or flavor, or both. With these juices, then, the study was directed toward special methods of con-

This bulletin will be of interest only to those concerned with the commercial manufacture of fruit juices. The methods given call for cold storage, sterilization in carbon dioxid, and other processes not commonly available to the housewife.

densing and keeping them by refrigeration or by the use of sterilization in carbon dioxid.

In this bulletin it is deemed best, therefore, to discuss first the general methods of extracting the juice and the ordinary forms of sterilization applicable to certain of these fruits, as a preliminary to the discussion of the special methods and their application to the juices of individual fruits.

GENERAL METHODS OF PREPARATION.

EXTRACTION OF JUICES.

Grinding.

If to be cold pressed, it is usually necessary to crush the fruit to facilitate the outflow of juice. Exceptions are the citrus fruits, which should be pressed after cutting in two, and pineapples, which may be pressed whole. Crushing is probably best effected by passing the fruits through an apple grater. The moving part of this machine, which is operated by power, consists of a rapidly rotating iron cylinder carrying short knives.

Heating.

To increase the juice yield, intensify the color, or impart the desired flavor to the juice, the fruit may be heated before pressing, in which case crushing may be omitted. Juices of the small fruits are successfully prepared with or without previous heating. Pineapples, peaches, and the citrus fruits should be cold pressed.

Heating is conveniently conducted in a steam-jacketed kettle made of copper with tin lining or in one of aluminum which should be fitted with a gate valve at the bottom for discharging the juice. To avoid scorching while heating, it is necessary to stir the fruit continuously.

Pressing.

The system of racks and cloths extensively employed in this country in the manufacture of grape juice and cider is probably also best for preparing the juices of other fruits. The fruit or fruit pulp is built up in the following manner, in the form of square masses called "cheeses," in heavy press cloths separated by racks. A square rack is placed on the press floor. On this is laid a square form, over which is spread the press cloth arranged diagonally, the corners lying on the sides of the form. The cloth is large enough to permit a depression to be made in the center and still inclose the pulp completely when the corners are folded over. In the depression is placed the ground fruit, which takes the shape of the interior of the form, thus making a square cake or "cheese." The corners of the cloth are folded over and, if necessary, pinned together. The form is then lifted off and another rack placed upon the cloth inclosing the "cheese." If desired another press cake may now be formed upon this rack, in which way a series of press cakes is built up until the

entire space between the press floor and the head of the press is filled.

Racks of hard maple are best, as this wood is very strong and quite flavorless. Extra heavy racks are required in pressing citrus fruits and pineapples. The press cloths should be of the extra-heavy quality, sold by manufacturers of cider and vinegar makers' supplies.

The rack-and-cloth method has the merit of affording an excellent opportunity for the drainage of the mass of fruit while under pressure. An additional advantage is the ease with which the press, racks, and cloths may be kept clean. After pressing it is usually necessary only to wash off the press bed and racks with a hose. When the pomace has been shaken out, the cloths are cleaned by hosing off and by an occasional washing. Racks and cloths must be kept dry when not in use. When operating continuously, racks and cloths are apt to become heavily charged with yeasts which infect the juices passing through and cause fermentation to occur very rapidly, in extreme cases even while pressing. This may be avoided by systematic daily cleansing of racks, cloths, and press.

The hydraulic type of press, operated by power, is very satisfactory. A steady but relatively light pressure is especially desirable in pressing the juice from the viscous masses formed by the ground pulp of peaches and of some of the small fruits.

REMOVAL OF SEDIMENT FROM FRUIT JUICES.

Newly expressed fruit juices are invariably turbid because of the suspended substances present. A convenient way for removing the greater part of the sediment consists in passing the juice through a milk separator, which causes a large portion of the sediment to adhere closely to the walls of the bowl. By filtering through paper pulp a perfectly clear juice may usually be obtained. Infusorial earth [1] is recommended by filter press manufacturers as an aid in the filtration of liquids which contain slime, and the experiments on fruit juices here considered indicate that this substance may be generally used in their filtration. The addition of 2 per cent or less of infusorial earth to a fruit juice will in many cases produce a perfectly clear filtrate, as the infusorial earth prevents the stopping up of the pores of the filter by the slimy suspended substances of the juice.

[1] Infusorial earth, also called diatomaceous earth, or kieselguhr, consists of nearly pure silica built up of the skeletons of microscopic sea animals called diatoms. When crushed and bolted it therefore exposes an enormous surface to liquids with which it is mixed. It possesses the property of opening up the slime which collects on the filter cloths, which otherwise would choke and render filtration impossible. Infusorial earth possesses this property to an extent not possessed by any other known substance. At the same time it is so inert that neutral or acid substances can be filtered through it practically without contamination. It is extensively mined in the United States and may be had finely bolted, ready for use in filtering, in carload lots at less than 2 cents a pound.

STERILIZATION OF FRUIT JUICES.

Containers of glass, porcelain, or tinned iron (tin cans) in which fruit juices may be sealed and sterilized are available. The juice may also be poured while very hot into sterilized wooden casks which are then sealed. Vessels of glass possess an obvious advantage in that a view of the contents may be had at any time without being opened.

GLASS CONTAINERS.

CARBOYS.

The process of sterilizing the juice in glass carboys consists in filling previously warmed 5-gallon carboys with hot juice and sealing them while hot. They are warmed, either by placing them for a time in a closet heated by steam pipes, or by partly submerging and rotating them in a bath of hot water. The juice is conveniently heated in the steam-jacketed kettle already described (page 2) and then poured into the hot vessel, leaving space for the stopper, which is forced tightly into position.

Experience shows that the contents of partially filled carboys spoil more readily than those of full carboys, doubtless due to the fact that in the former the surface of the cork, which is further removed from the surface of the hot juice, does not receive the necessary heat treatment. When carboys of juice become infected, it is usually possible to trace the infection to the growth of organisms on the surface of the cork. It is, therefore, clear that the corks should be sterilized as completely as possible before use. Successful sterilization of the cork is somewhat difficult to accomplish. A satisfactory method consists in dipping the corks in melted paraffin, removing and then heating them in a steam closet for several days, during which time the paraffin is gradually absorbed. The corks should be steamed for a few moments or dipped in scalding water immediately before use.

After cooling, the carboys should be transferred to racks in a cool place where they can be inspected at frequent intervals. Such examination is imperative, as, in spite of the precautions described, a small portion of the juice usually shows evidence of infection, in the form of patches of mold floating on the surface. The flavor is often greatly injured and the juice rendered worthless by such infection. Before the colony of mold has become larger than a small dot floating on the surface, it should be removed and the juice sterilized. The advantage of the transparency possessed by glass containers is here evident. If development of yeasts, with the consequent bursting of carboys, occurs, serious defects in technique are probable, as yeasts in fruit juices are very easily killed by heating.

BOTTLES.

Flat-bottom bottles, ranging in capacity from 1 pint to 2 quarts, form the standard container in which fruit juices are at present offered for sale at retail. Together with the glass fruit jar so widely used in canning fruits in homes, they constitute the containers in which fruit juices are most easily sterilized on the small scale. The bottles may be filled with hot or cold juice as desired. If filled with cold juice, allowance must be made for expansion on heating and the bottles can not be filled as full as when warm juice is used. If filled with hot juice, they may be sterilized by being placed in a bath containing hot water and kept at the temperature desired. If filled with cold juice, it is necessary to place them in a bath filled at first with cold or lukewarm water, which is then rapidly heated to the temperature desired. Starting in this way and using a water bath heated by a steam coil, it is found that about half an hour is usually required for the contents of the bottles to reach the water bath temperature.

Bottles are easily sealed with corks, patent seals, or porcelain stoppers. Corks, which are best placed in position by means of a corking machine, must be given the treatment already described or one equally effective, before being used. They must be held securely in position during the heating. The method of binding a cloth firmly over the cork and tying it with a string is found to be much more easily applied than that of merely tying it with string or wire or using various types of cork holders. As patent bottle seals do not require tying during the heating, they are more convenient. Porcelain stoppers, once correctly fitted to the bottles, are very satisfactory in the preparation of fruit juices for home consumption, and by renewing the rubber washers may be used repeatedly. The bottles should be placed on their sides in the water bath, so that the inner surfaces of the corks receive the heat treatment while in contact with the juices. If this precaution is not taken, the chances of spoilage by mold growth are measurably increased.

On the whole, it is not improbable that fruit jars will prove more satisfactory as containers in sterilizing fruit juices on the domestic scale than bottles, because of the difficulties involved in using corks. Methods successfully employed in heating fruit in jars, or sealing it in jars while hot, work equally well for the corresponding fruit juices.

Wooden Containers.

Wooden casks are useful as containers in which fruit juices are to be kept for a limited time after sterilization. It is, however, difficult to sterilize the casks thoroughly before filling them with hot juice and to keep the juices in them sterile after they are filled and sealed. If large casks are used, the juice remains hot for a long time, thus

receiving a heat treatment much longer than necessary, which may injure the flavor. Another objection to casks is that the color and flavor of the juices are injured by the gradual solution of extract from the walls of the container. Wooden casks can not, therefore, be generally recommended as containers for fruit juices.

Tin Cans.

Juices may be far more easily sterilized in cans than in wooden casks. Cans, however, can not at the present time be generally recommended, as experiment shows that the tin is constantly dissolving in the juice, even when the type of can designated as "enamel lined" is used. There is consequent injury to color, in case of delicately tinted juices, and the flavor also is often injuriously affected. The ease with which juices are sealed and sterilized in tin cans, however, makes it seem probable that they may be successfully used in special instances for storage of sterilized juices, during limited periods at least.

Temperatures and Times of Heating.

In cooking the fruit pulp in the kettle the temperature does not exceed 95° C. (203° F.) during the time ordinarily required to reduce the fruit to a pulp, usually less than 5 minutes. In heating juice to be transferred to hot carboys the temperature should be carried up to from 85° to 90° C. (185° to 194° F.). The sterilizing temperatures here recommended for general use in preparing fruit juices are higher than those used in the earlier part of the experimental studies to be described later. In this work it was found that while at times complete sterilization was effected at a temperature of 70° C. (158° F.), or even lower, upon other occasions mold developed. Employment of higher temperatures resulted in almost wholly eliminating the difficulties of mold growth in juices heated in bottles.

A temperature of at least 80° C. (176° F.) is recommended for all fruit juices sterilized in bottles, allowing, when starting with cold juice, half an hour for the juices to attain bath temperature, and keeping the bottles at this point for at least half an hour. Where it is found that no injury to flavor results, this temperature may be increased with advantage. Usually merely filling the bottles or fruit jars with the boiling-hot juice and sealing them immediately is satisfactory. An exception, however, to this treatment is found in the case of lemon juice, the flavor of which is much injured by heating to 80° C. This juice is easily sterilized, without serious injury to the flavor, by being heated to 70° C. for half an hour, allowing half an hour for the juice to attain bath temperature.

With juices sterilized in carboys the situation is less satisfactory, as infection with molds often occurs when all of the precautions already described have been taken. The method of sterilizing

juices in carboys, therefore, requires further study. It is not improbable that a method of sealing in which no air space remains in the carboy, or in which no oxygen is present in the gases above the juice surface, would result in the complete arrest of the development of molds.

SPECIAL METHODS OF PREPARATION.

As has been stated, the methods of handling just described can be successfully applied to but a limited number of those juices tried, namely, black raspberry, blackberry, black currant, sour cherry, and peach. In the case of strawberry, apple, and other juices which are greatly injured in distinctive flavor by being heated, it is possible to retain the flavor satisfactorily by keeping the juice in freezing storage at a temperature of 14° F. Although certain juices, as pineapple and orange, are not greatly injured in flavor by sterilization, they change in flavor and color upon being kept at ordinary temperatures after sterilization. Keeping such juices in cold storage at from 32° to 36° F. causes satisfactory retention of the color and flavor. Another cold-storage method of general application to fruit juices, and one particularly valuable for fruit juices the distinctive characters of which are injured by heat, is the method of concentrating by freezing.

Juices of oranges, lemons, and pineapples darken greatly in color if sterilized and subsequently kept in contact with atmospheric oxygen. Satisfactory color retention can here be had by sterilizing and keeping the juices free from atmospheric oxygen, which is most conveniently effected by carbonating slightly and sterilizing them in carbon dioxid.

APPLICATION OF COLD STORAGE TO FRUIT JUICES.

Storage of Raw Juices at 32° to 35° F.

Apple juice, cooled quickly after pressing to 32° F., and stored at this temperature, will keep for from 6 weeks to 3 months before it ferments sufficiently to be considered hard or sour.[1] Unpublished experiments on the keeping of raw orange juice at from 32° to 35° F. show that its flavor deteriorates quite rapidly. An unfavorable feature of storage of raw fruit juices at from 32° to 35° F. is the development of molds at juice surfaces. It is not improbable that simple measures for the suppression of the mold growths could be successfully used, as, for example, keeping the containers entirely filled, or keeping the juice surfaces well blanketed with a layer of carbon dioxid, or possibly using ultraviolet light. It seems probable, however, that cold storage of freshly expressed juices at from 32° to 35° F. is of but limited application, as the activities of microorganisms are not sufficiently held in check.

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[1] U. S. Dept. Agri., Bureau of Chemistry Cir. 48.

Cold Storage of Sterilized Juices at 32° to 35° F.

Experiments which consisted simply of keeping bottled sterilized juices at from 32° to 35° F. indicate that certain fruit juices, notably orange, pineapple, and currant, retain their color and flavor far better at low temperatures than at the temperatures of ordinary storage.

Freezing Storage of Raw Juices.

Juices may be kept in freezing storage at temperatures approximating −10° C. (14° F.) for many months without marked change in composition or flavor or development of microorganisms.

CONCENTRATION BY FREEZING.

Upon freezing a fruit juice, ice separates, the juice becoming correspondingly concentrated. As the temperature falls lower and lower, more and more ice forms, and the nonfrozen liquid becomes more and more concentrated, until finally a solid block of frozen fruit juice, consisting of ice and concentrated, sirupy liquid, results. If the block of frozen fruit juice is now coarsely broken up and centrifugalized, the sirup can be removed from the ice, and the latter discarded. A concentrated fruit juice possessing the color and flavor of the original fruit is thus obtained.

In freezing the juices are placed in containers having slightly flaring sides, so that by warming the sides and bottom the block of frozen juice may be easily removed. Slow freezing is more satisfactory than rapid freezing in an ice-cream freezer, as in the former instance the crystals of ice formed are large, consisting toward the end of the freezing of long, thin plates reaching in toward the center of the container, while in the ice-cream freezer the ice forms a finely felted mass from which the concentrated juice is separated with difficulty. On the laboratory scale the crushing and centrifugalizing is best carried on in a cool room, thus avoiding undue melting. On a commercial scale this precaution is not so necessary. Temperatures approximating −10° C. (14° F.) are sufficiently low to give to concentrated juices a solids content of about 50 per cent. Such juices ferment very slowly at room temperatures, the presence of sugar and acid retarding greatly the growth of microorganisms.

The method may be easily extended to commercial proportions, as ice crushers and centrifugals, readily obtainable in the market, can be used without modification.

STERILIZATION IN CARBON DIOXID.

In Carboys.

The carboys are filled nearly full with the cold juice to be sterilized and placed in a bath of cool water. The bath temperature is rapidly brought up to the point at which it is desired to sterilize the product, while a stream of carbon dioxid is slowly passed into each carboy

through a glass or block tin delivery tube reaching nearly to the bottom. When the desired temperature has been reached, the flow of carbon dioxid is momentarily increased, the delivery tube being withdrawn at the same time and a paraffined cork stopper, taken from scalding water, instantly inserted.

In Bottles.

The juice is cooled to refrigerator temperatures in a cask and a current of carbon dioxid passed through until the product tastes distinctly of the dissolved gas. It is then transferred to the bottles. The air above the surface of the juices in the bottles is displaced by a rapid current of carbon dioxid after which the cork is instantly forced into position, tied in place and the bottles and contents given the necessary heat treatment. By thus lightly carbonating, excessive pressures due to carbon dioxid are not developed on heating.

The principal effect of thus excluding atmospheric oxygen by carbon dioxid is the satisfactory retention in color observed in citrus and pineapple juices. The products are at the same time improved in palatability by the presence of carbon dioxid.

EXPERIMENTAL WORK.

A condensed summary of the experimental work with the different fruit juices taken from the laboratory notes follows. Except where noted to the contrary, the conclusions are based on the work of three or more successive seasons.

STRAWBERRY JUICE.

Locally-grown berries, variety Gandy, were used in most instances.

Pressing.—To secure good yields it was necessary to grind before pressing, the pressure being applied very gradually to allow time for drainage. The yields ranged from 63 to 88.06 per cent.

Sterilization.—The juices were sterilized without injury to color, but with marked injury to fresh fruit flavor. A cooked strawberry taste developed.

Keeping after sterilization.—Color and flavor changed greatly on keeping the juice in common storage, even in carbon dioxid. The beautiful, bright, red colors faded to dull brownish-red tones, and all distinctive flavor of strawberry disappeared, except for a slight cooked strawberry aroma. Disagreeable flavors developed upon prolonged storage at common temperatures.

Keeping in freezing storage and concentration by freezing.—Raw strawberry juice retained well its original color and flavor in freezing storage at −10° C. (14° F.) for nearly 8 months. The juice could be concentrated easily by freezing, but when partly concentrated became gelatinous, the juice and ice separating with difficulty.

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Discussion.—The preparation of strawberry juice by sterilization methods can not be advised because the distinctive flavor of fresh strawberries is greatly injured by sterilization. During the period of keeping it at ordinary temperatures after sterilization, further deterioration in flavor, accompanied by fading of color, occurs.

RED CURRANT JUICE.

Red currants grown in New York State, mostly of the Fay variety, were used.

Pressing.—Yields varying from 65.5 to 72.8 per cent were obtained by passing currants through the apple grater and pressing them without previous heating. Yields from 73.2 to 81.3 per cent were obtained by cooking before pressing.

Sterilization.—Upon heating, slight but distinct loss in fruitiness occurred. The color was unchanged.

Keeping after sterilization.—On keeping in storage at room temperatures after sterilizing them, the juices very gradually lost in distinctive flavor as well as in color. The sterilized juices kept in cold storage, at from 32° to 35° F., retained their color and flavor very well.

Storage of raw juices at freezing temperatures and concentration by freezing.—The color and flavor of raw currant juices kept in freezing storage at 14° F. were well retained. Juice concentrated by freezing formed an intensely acid liquid, keeping well the color and flavor of the original juice.

Jelly making from sterilized juices.—Well-flavored jellies, possessing clean, sharp, acid tastes, were invariably obtained. The jellies prepared from the sterilized juices kept in cold storage were much more brilliantly colored than those from the same juices kept in common storage. Jellies prepared from cold-pressed juices were less firm than those made from the hot-pressed juices. The latter, however, were not stiff enough to hold their shape well.

Discussion.—Juice from red currants is best prepared by cooking until soft and pressing. The juices are then freed from sediment and sterilized in glass. For the preservation of color it is necessary to keep them at low temperatures. Temperatures of from 32° to 35° F. are satisfactory. Red currant juices are much too acid for use as beverages without dilution and sweetening, in this respect resembling strawberry juice, though more acid. The freezing storage methods work well, but are hardly necessary, as color and flavor are well retained during sterilization.

BLACK CURRANT JUICE.

Black currants, variety not determined, grown near Geneva, N. Y., were used.

Pressing.—It was necessary to heat the fruit before pressing to secure a satisfactory yield and quality of juice. The yields of hot pressed juice ranged between 68.4 and 78.1 per cent.

Sterilization and keeping after sterilization.—The characteristic color and flavor were well retained in juices sterilized and kept after sterilization at ordinary temperatures, even for periods as long as several years.

Application of special methods.—Keeping the juice after sterilization at low temperatures or in carbon dioxid did not result in a product perceptibly better in quality than did keeping it under usual conditions where, as stated before, the distinctive qualities were excellently well retained. Upon concentration by freezing, a very viscid highly acid concentrate was obtained.

Jelly making from sterilized juice.—Excellent jellies were easily prepared from sterilized black currant juice by adding an equal weight of sugar and cooking.

Discussion.—Juice of black currants may be prepared readily by cooking, pressing, and sterilizing in sealed containers. It is practically unaffected in color and flavor by sterilization, and the color and flavor are well retained. Application of special methods to secure the retention of color and flavor is therefore unnecessary.

BLACKBERRY JUICE.

The data are based on results obtained with wild blackberries and with the following cultivated varieties: Eldorado, Early Harvest, and Erie.

Pressing.—Cooking before pressing increased the yield and gave juices possessing the desirable aroma and flavor of cooked blackberries. It was necessary to apply the pressure very gradually to avoid pressing the pulp through the press cloths. Yields when cold pressed ranged from 66.9 to 69.6 per cent; hot pressed, from 74.4 to 80. 9 per cent.

Sterilization.—The juices lost but little in flavor and color on being sterilized.

Keeping after sterilization.—Upon being kept at ordinary temperatures after sterilization the distinctive blackberry color and flavor were well retained for a period of at least 6 months. On keeping for longer periods the flavor gradually lost its blackberry character, and the color slowly faded. Juice kept at from 32° to 35° F. and in carbon dioxid after sterilization was not perceptibly superior in distinctive flavor and color to that kept at ordinary temperatures in air.

Concentration by freezing.—The juice was easily concentrated by freezing.

Discussion.—A satisfactory method of preparing the juice of wild or cultivated blackberries based on the foregoing results consists in cooking the berries, pressing them, freeing the juice from sediment and sterilizing it in bottles. Though quite acid, juices of both wild and cultivated varieties are attractive when so prepared.

BLACK RASPBERRY JUICE.

Locally-grown berries of the Doolittle and Kansas varieties were used.

Pressing.—Upon being pressed without previous heating, yields of from 61.8 to 75 per cent of juice were obtained. Yields as high as 76.18 per cent were secured by hot pressing. Pressure must be applied very gradually for satisfactory yields.

Sterilization.—The juices were not injured perceptibly in flavor or in color by sterilization.

Keeping after sterilization.—Juices prepared by either hot or cold pressing retained their color and flavor, which were practically unchanged for prolonged periods at common temperatures. Special measures, such as keeping at low temperatures or sterilizing in carbon dioxid, are therefore not necessary.

Concentration by freezing.—Upon concentrating black raspberry juice by freezing, a peculiar coagulum formed, consisting apparently of flocculated coloring matter. Concentrating by freezing as applied to black raspberries did not appear to be of particular value, in view of the excellent color and flavor retention of the juice when sterilized and kept at room temperature.

Discussion.—Juices can thus easily be prepared from black raspberries by crushing and then pressing them with or without previous heating. The characteristic color and flavor of black raspberry juice are excellently well retained upon sterilizing it and keeping it after sterilization at ordinary temperatures for prolonged intervals, even as long as several years. The sterilized juice is rather acid, requiring the addition of sugar to make it palatable.

RED RASPBERRY JUICE.

Locally-grown berries of the Miller, Brandywine, and Cuthbert varieties were used.

Pressing.—High yields of juice, ranging from 71.9 to 82.3 per cent, were easily obtained by crushing and pressing the berries. It was necessary to press slowly and to use double press cloths.

Sterilization.—Although red raspberry juices underwent a distinct change in flavor on heating, the palatability of the juice was not greatly injured.

Keeping after sterilization.—The color faded and disappeared and the flavor changed greatly, even during storage periods of 6 months. Bottling the juice in carbon dioxid and keeping it in cold storage at from 32° to 35° F. after sterilization had no apparent effect in retarding these changes in color and flavor.

Keeping raw juice in freezing storage.—The color and flavor were excellently well retained.

Concentration by freezing.—The color and flavor were well retained. Highly colored, richly flavored, very acid juices were obtained.

Discussion.—The color and flavor, while thus found to be injured but slightly by sterilization, deteriorate greatly on keeping, even though carbonated and kept in cold storage. Only in freezing storage are the color and flavor satisfactorily retained. It is, however, possible to keep red raspberry juice by freezing storage methods.

PINEAPPLE JUICE.

Florida-grown red Spanish pineapples were used in all cases.

Pressing.—High yields of juice were invariably obtained. Juice derived from the peels possessed rather disagreeable soapy flavors. Fresh pineapple juice prepared from crushed unpeeled pineapples was, therefore, less attractive than that from pineapples which were peeled before being pressed. It was found, however, that pineapples which had not been peeled or previously crushed, but the crowns of which had been removed, might be placed on their sides in cloths on extra heavy racks and pressed. So prepared, the juice was not perceptibly injured by off flavors derived from the peel.

Effect of heating on flavor.—Although heating the juice caused slight but definite changes in flavor, it did not markedly injure the juice.

Effect of storage on color and flavor.—Gradual darkening occurred where precautions were not taken to exclude atmospheric oxygen in bottling. This color change was controlled by bottling the juice in carbon dioxid. In addition to this, carbon dioxid imparted an agreeable flavor to the juice, simulating the freshness of the original fruit. When stored at common temperatures, the gradual development of a peculiar taste, designated as a stale flavor, occurred, and much of the rich flavor of the original juice disappeared. The characteristic flavor, however, was sufficiently well retained for recognition of the juice as pineapple. Cold storage at from 32° to 35° F. prevented perceptible losses in flavor during a period of 7½ months.

Storage at freezing temperatures.—During storage at freezing temperatures, $-10°$ C. (14° F.), the color and flavor were well retained.

Special methods.—A voluminous precipitate formed on heating pineapple juice. A treatment consisting of warming the juice to 85° C. and allowing it to stand for one hour was sufficient to completely precipitate the heat-coagulable substances. The bulk of the coagulum was removed by passing the cooled juice through the milk separator. Filtration through paper pulp was thus greatly facilitated, as clogging of the filter was retarded by the removal of the coagulum.

Discussion.—It is necessary to take special precautions in the preparation and storage of pineapple juice to prevent deterioration in distinctive color and flavor. Sterilization and the subsequent keeping of the juice free from contact with atmospheric oxygen result

in satisfactory color retention. Keeping it in cold storage at from 32° to 35° F. after sterilization causes a satisfactory retention of distinctive pineapple flavor. A heat treatment, consisting in heating to about 85° C. for an hour, is sufficient to precipitate the coagulable matter. This should be followed by prompt cooling. Removal of most of the suspended matter by use of the milk separator facilitates subsequent filtration. A perfectly brilliant juice of very attractive pineapple flavor is then easily obtained by filtering, carbonating lightly, and finally sterilizing.

CHERRY JUICE.

The English Morello variety grown near Geneva, N. Y., was used in all cases.

Pressing.—High yields of juice, ranging from 73.4 to 80.4 per cent, were easily obtained by pressing the crushed cherries without previous heating.

Sterilization and keeping after sterilization.—The distinctive color and flavor were well retained when heated in carboys, racked into bottles, resterilized, and afterwards kept at room temperatures.

Discussion.—Juice from English Morello cherries can thus be successfully prepared by the usual methods. Juice prepared from cherries crushed, kernels and all, before pressing, was slightly better than juice prepared without crushing the kernels, because it possessed flavors derived from the kernels.

PEACH JUICE.

Georgia-grown peaches were used in all cases. The varieties were Carman, Hiley, and Elberta.

Pressing.—Juices were prepared readily by crushing and pressing the fruit. They were quite viscous, and long, slow pressings were necessary. If the kernels were crushed before pressing a marked pit flavor appeared in the juice.

Sterilization and keeping after sterilization.—The prepared juices lacked somewhat in distinctive peach flavor, but no evidence of deterioration of flavor on sterilization or keeping after sterilization was found.

Filtering.—The addition of less than 1 per cent of infusorial earth to peach juice rendered it readily filterable.

Discussion.—Upon the whole, peaches are somewhat less promising as a source of juice than many other kinds of fruit. Juices of tree-ripened peaches should, however, be tried before final conclusions are drawn.

HUCKLEBERRY JUICE.

The species *Gaylussacia baccata* was used. One season's work only was carried on.

Huckleberries yielded their juice readily when pressed either with or without previous heating. Juice prepared from berries not heated

before pressing lacked in distinctive flavor; that from cooked fruit possessed a distinctive aroma which was not well retained on keeping. It was intensely colored. Upon the whole, huckleberries are not of promise as a source of juice.

LEMON JUICE.

California-grown lemons were used in all of the studies.

Pressing.—The juice was prepared readily by cutting each lemon transversely into two or more pieces, placing the fruit in cloths between racks and pressing it. Extra heavy or double racks are required. Good yields of juice, ranging from 35 to 40 per cent by weight of the lemons, were obtained.

Removal of sediment.—A large proportion of oil was removed from the skins in pressing. This was removed by passing the juice through a milk separator, which at the same time removed a portion of the matter suspended in the juice. Finally, the juice was rendered almost clear by filtering it through paper pulp. Infusorial earth can be successfully used in preparing clear juices.

Sterilization and keeping after sterilization.—The juice was sterilized without marked loss in flavor by heating it to 70° C. for half an hour. When kept at low temperatures it retained well a rich lemon flavor for many weeks. Sooner or later, however, a peculiar flavor, designated as the "bottled lime-juice" flavor, made its appearance, the typical lemon flavor at the same time becoming less conspicuous. Simultaneously, darkening in color occurred unless special measures were taken to protect the lemon juice from contact with the air. By bottling in carbon dioxid before sterilizing the juice, satisfactory color retention was secured. Oxygen may also be successfully kept from contact with the juice by sealing the containers in vacuum. The exclusion of air, however, had no perceptible effect on the retention of flavor. So far as tried, keeping the juice in cold storage, at from 32° to 35° F., was not successful in controlling the flavor change.

Concentration of lemon juice by freezing.—Lemon juice is readily concentrated by freezing. As lemon juice is easily sterilized without marked injury to flavor, however, it is anticipated that the method of concentrating by freezing will be of little value here.

Discussion.—Up to the present time the department is not in a position to suggest a satisfactory method for the preparation of lemon juice, as none has been found for properly retaining the characteristic lemon flavor during keeping at ordinary temperatures.

Flavor is quite well retained, however, for at least several weeks. Other features of the problem of preparing lemon juice have been mastered. Satisfactory yields of juice are invariably obtained by cutting and pressing. Color retention is assured if the juice is lightly carbonated, and boiled and sterilized in carbon dioxid.

The milk separator can be used in removing oil and the bulk of the suspended matter. Preliminary experiments show that the addition of infusorial earth to the juice will make possible the preparation of a brilliant juice entirely free from suspended matter or sediment.

ORANGE JUICE.

Florida- and California-grown oranges were used.

Pressing.—Pressing was successfully accomplished by cutting each orange transversely into two or more pieces, forming the cut fruit into "cheeses" (p. 2) in cloths and then pressing it. Extra heavy or double racks were required. Removing the peels before pressing was found inadvisable, as juices so prepared were deficient in orange flavor, and cooked tastes, developed during sterilization, were more prominent than in juices prepared from unpeeled fruit. In a typical experiment with Florida oranges the yield of juice was 52.7 per cent.

Sterilization and keeping after sterilization.—The juice underwent a slight but distinct change in flavor on being sterilized at 80° C. When afterwards kept at temperatures of from 32° to 35° F., no further flavor change occurred for many months. When kept at ordinary temperatures, however, marked flavor deterioration occurred. The flavor changes were accompanied by darkening of color, which, however, could be controlled by carbonating the juice and sterilizing it in carbon dioxid. The suggestion of excluding the air from contact with the surface of orange juice to control color change is due to R. F. Bacon, formerly of the Bureau of Chemistry. It has been tried with other fruit juices, and, as already described (p. 7), found useful in the case of lemon and pineapple juices. Carbonating or keeping in carbon dioxid had no effect on the retention of the distinctive flavor of orange juice.

Removal of sediment from orange juice.—Freshly expressed orange juice contained much suspended matter which detracted from the appearance of the sterilized juice. Experiments consisting in passing the juice through the rotating bowl of a milk separator showed that a large part of the suspended matter can be easily removed. A small portion of the juice carrying the orange oil passed from the separator through the cream screw. A certain amount of this juice, added to the main body of juice which has passed from the milk separator through the milk screw, restored the flavor of orange oil to the juice to the degree desired. Infusorial earth added to orange juice promotes filtration.

Freezing and thawing orange juice.—Upon freezing orange juice and allowing it to thaw, more or less complete coagulation of suspended matters occurred. This fact is possibly of importance in the development of the technique of preparing a clear orange juice of satisfactory flavor.

Concentration by freezing.—Concentration to a sirup was easily accomplished.

Discussion.—The studies on orange juice have not led to results on which a method for its preparation may be based, as no way to successfully retain fresh orange juice flavor has been found. Sterilizing the juice injures the flavor, which continues to deteriorate gradually when the juice is kept at ordinary temperatures. In cold storage, however, the flavor is well retained. Certain features of the technology of preparing orange juice have been mastered. Thus, the milk separator may be successfully employed in removing excessive amounts of oil as well as suspended matters from freshly expressed juice. Carbonating and sterilizing the juice in carbon dioxid, as well as cold storage at from 32° to 35° F., permit of satisfactory color retention. Concentration by freezing to a sirup is of promise, but this subject, as well as the use of infusorial earth in filtering, remains to be further worked out experimentally.

SUMMARY.

Pressing.

Satisfactory yields of juice were easily obtained from all of the fruits studied. Lemon and orange juices were best expressed by cutting each fruit into several pieces and then pressing, a method which could be successfully used in pressing pineapples, although the method of pressing the fruit without previous cutting is probably superior. It was found advisable to pass all of the other kinds of fruit pressed without heating through an apple grater to facilitate the outflow of the juice.

Heating before pressing in the case of black raspberry, blackberry, red currant, black currant, and huckleberry juices resulted in larger yields of juice and the development of more color and a more distinctive flavor than were obtained from cold pressing. Strawberries, red raspberries, cherries, peaches, pineapples, lemons, and oranges were cold pressed.

Effect of Heating on Distinctive Colors and Flavors.

Heating the juices sufficiently to sterilize them did not affect injuriously the color of any of the fruit juices, though pineapple, lemon, and orange juices usually darkened somewhat if heated in the presence of dissolved oxygen or if exposed to atmospheric oxygen during the heat treatment.

The distinctive flavor of the fresh fruit was greatly injured and the familiar cooked strawberry taste appeared when strawberry juice was sterilized by heat. The fresh fruit flavor of orange juice was also distinctly injured when the juice was heated. Although all lost in the quality of freshness, heating did not seriously affect the flavor

of other fruit juices, except in cases where the heat employed was excessive.

RETENTION OF DISTINCTIVE COLORS AND FLAVORS.

The extent to which color and flavor were retained on keeping the juice after sterilization varied greatly in the juices from the various fruits.

In strawberry juice the brilliant red color of the freshly sterilized juices in all cases faded greatly and further flavor losses occurred. Sterilization and subsequent keeping in carbon dioxid were not effective in securing color retention.

Red currant juice very gradually lost in distinctive color and flavor on being kept at room temperatures after sterilization and keeping in carbon dioxid was not effective in securing either color or flavor retention. Cold storage at from 32° to 35° F. was found to be a very satisfactory means of controlling color and flavor changes.

The distinctive colors and flavors of black currant, blackberry, and black raspberry juices were satisfactorily retained during prolonged periods at common storage. The flavor of blackberries was, however, distinctly less well retained than that of black currants or black raspberries, though it did not undergo a perceptible change during a storage period of six months.

In the case of red raspberries the distinctive color and flavor were poorly retained, even on keeping the juice in carbon dioxid in cold storage at from 32° to 35° F.

When sterilized and subsequently kept in carbon dioxid the distinctive color of pineapple juice remained practically unchanged. When exposed to atmospheric oxygen at juice surfaces during and after sterilization, marked darkening occurred. Change in color was also found to be greatly, though not wholly, retarded by keeping the juice in cold storage at from 32° to 35° F. On keeping the juice at ordinary temperatures the distinctive pineapple flavor gradually lessened, though the juices remained recognizable as pineapple. By keeping in cold storage at from 32° to 35° F. flavor change was almost wholly prevented.

The distinctive colors and flavors of peach and cherry juices were quite well retained while kept at room temperatures. Huckleberry juice, hot pressed, lost in flavor on keeping.

Lemon juice darkened in color if sterilized and kept in the presence of atmospheric oxygen, though the color was satisfactorily retained when the juice was sterilized and kept in carbon dioxid or in vacuum. In all cases an off-flavor, designated as a "bottled lime-juice" flavor, appeared in the lemon juice after it had been kept for a time after sterilization, even though in cold storage at from 32° to 35° F.

Orange juice also underwent a marked darkening in color when kept at room temperatures after being sterilized. The color was fairly well retained when atmospheric oxygen was excluded by sterilizing the juice and subsequently keeping it in vacuum or in carbon dioxid, and the change in color was well controlled by keeping the juice at low temperatures. The flavor of sterilized orange juice, already slightly injured by the heating necessary for sterilization, underwent further changes when kept at room temperatures. It was found that by keeping the juice in cold storage at from 32° to 35° F. the flavor was well retained for long periods.

Keeping in Freezing Storage and Concentration by Freezing.

The distinctive colors and flavors of all fruit juices kept in freezing storage at about $-10°$ C. (14° F.) were found to remain practically unchanged during many months, except that a peculiar coagulation of much of the coloring matter appeared in the juice of the black raspberry. It was possible to concentrate fruit juices to sirups by freezing out the water as ice and centrifugalizing. Characteristic colors and flavors were well retained on concentrating.

Filtering.

Infusorial earth greatly promotes the filtering of fruit juices, as it retards greatly the clogging of the filter.

CONCLUSION.

Juices of red and black currants, blackberries, black raspberries, sour cherries, and peaches may easily be successfully prepared on the large scale by the methods used for the preparation of grape juice, as they retain their characteristic properties well on being sterilized and stored away. Strawberry juice and red raspberry juice are not suited for preparation on the large scale because of the readiness with which the distinctive colors and flavors change. Huckleberry juice is somewhat characterless. Pineapple juice requires special methods for its successful preparation not necessary in case of the other juices. Its preparation on the commercial scale, however, is of marked promise.

Satisfactory methods for the preparation of lemon and orange juices have not been developed. The peculiar change in flavor of lemon juice stored after sterilization, even at low temperatures, is an obstacle to be overcome before the preparation of the juice on the large scale can be considered advisable. The problem of preparing orange juice is not without promise. It is not unlikely that highly specialized methods in which cold storage will play a prominent, if not dominating, part will be required.

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 242

Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.
June 19, 1915.

CORN, MILO, AND KAFIR IN THE SOUTHERN GREAT PLAINS AREA: RELATION OF CULTURAL METHODS TO PRODUCTION.

By E. F. Chilcott, W. D. Griggs, and C. A. Burmeister, *Assistants, Office of Dry-Land Agriculture.*[1]

CONTENTS.

INTRODUCTION.

This bulletin embodies the results of a study of methods of production of three important feed crops—corn, milo, and kafir—at three field stations on the southern Great Plains. The data presented have been obtained at Garden City, Kans., and at Dalhart and Amarillo, Tex. Experimental work with these crops has been conducted at Akron, Colo.; Hays, Kans.; and Tucumcari, N. Mex.; but the results obtained at these stations are not included in this study. At Akron very little grain has been produced by either milo or kafir, and it is generally conceded that this station is beyond the northern limit at which these crops can be profitably grown at this altitude. At Hays the small size of the plats used in the experimental work has subjected milo and kafir to influences, such as ravages by insects, that are not ordinarily experienced under field conditions. The data are therefore not sufficient to permit adequate com-

[1] During the progress of this work, the following assistants in the Office of Dry-Land Agriculture have had charge of the details of the investigations: R. W. Edwards, 1911 and 1912, and J. G. Lill, 1913 and 1914, at Garden City, Kans.; F. L. Kennard, 1908 to 1910, and C. B. Brown, 1913 and 1914, at Dalhart, Tex.; and L. E. Hazen, 1911 and 1912, at Amarillo, Tex. The work at Amarillo, Tex., is in cooperation with the Office of Cereal Investigations of the United States Department of Agriculture, while at Garden City, Kans., it is in cooperation with the Kansas Agricultural Experiment Station. The Biophysical Laboratory has cooperated in obtaining the meteorological data reported.

NOTE.—This bulletin is intended for all who are interested in the agricultural possibilities of the southern Great Plains area.

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parison either of the crops grown here and at other stations or of different methods of producing them at this station. Better yields have been obtained with corn at both of these stations, but as there are no results from other crops with which to compare them they are not given in this publication. At Tucumcari the work has not been carried on for a sufficient length of time to obtain averages or to warrant the drawing of definite conclusions. It is probable, however, that what may be said of crops at the other three stations under consideration will, in a general way, also apply to the Tucumcari district.

With this brief statement the work at these three stations will not be further considered, and the study will be confined to the results obtained at Garden City, Dalhart, and Amarillo. Although these stations are located some distance apart, they are confronted by general problems that are much the same, the local differences being in their intensity rather than in their nature. In order that the characteristics of this section may be more clearly understood, a brief account of the climatic and soil conditions is given here.

CLIMATIC CONDITIONS.

In a general way the climatic conditions at each of these three stations, in so far as they materially influence crop results, may be briefly described as follows: A limited annual rainfall of irregular distribution, a high wind velocity, a very high rate of evaporation, possible hail, and in the higher altitudes violent fluctuations in temperature. All of these factors will be discussed separately and for each station under consideration.

PRECIPITATION.

Rainfall is the most important factor influencing crop production in this section. In determining its influence, it is important that the distribution be considered as well as the total quantity. In a great many instances the distribution may have even greater influence than the total annual precipitation in determining crop production. It frequently happens in the case of torrential rainfall that a large percentage of the water will be lost by run-off. On the other hand, frequent light showers may at the end of the year give a large aggregate rainfall. These light showers wet only the surface soil, and the moisture may be lost by evaporation before another shower falls. Consequently, light showers may be of little value to growing crops. In any study of annual precipitation records of the distribution must be considered before its effects can be completely understood. To afford some means of general comparisons, the annual rainfall record for each of these three stations is given in Table I.

At Garden City the average annual precipitation for the years 1897 to 1914, inclusive, was 19.64 inches. At Dalhart, for the years 1908 to 1914, inclusive, the average annual precipitation was 15.92 inches. At Amarillo precipitation records are available for the 23 years from 1892 to 1914, inclusive. These records show that the average annual precipitation was 20.95 inches.

TABLE I.—*Monthly, annual, and average precipitation at Garden City, Kans., and at Dalhart and Amarillo, Tex., for the years stated.*

[Data in inches. Records for 1897 to 1907, inclusive, at Garden City, and for 1892 to 1906, inclusive, at Amarillo, were furnished by the United States Weather Bureau.]

Station and year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Garden City, Kans.:													
1897	0.01	2.33	0.19	2.09	0.61	3.19	3.49	5.80	0.33	1.78	[1] T.	0.50	20.32
1898	1.55	0	.50	.97	6.49	6.39	2.59	2.04	4.24	.43	1.55	2	28.75
1899	.35	1.18	1.30	1	.42	4.40	6.21	1	1.93	.75	1.26	.78	20.58
1900	.15	.88	1.22	5.20	2.05	2.79	2.18	.80	3.10	.52	T.	.40	19.29
1901	.20	.55	2.20	3.90	1.20	1.30	1.48	2.03	4.57	.60	0	.31	18.34
1902	.25	.87	2.46	.70	6.26	2.43	.98	.88	1	2.62	.20	1	19.65
1903	.25	4.45	.70	5.10	1.49	2.83	.77	3.65	.35	.40	.40	.25	20.64
1904	.10	T.	.11	.95	4.30	2.64	5.65	1.32	3.39	1.20	.09	1.30	21.05
1905	1.10	.71	1.30	5.70	1.47	4.57	.86	.57	1.05	.55	3.10	.05	21.03
1906	.30	.43	1.60	3.24	1.92	4.47	5.82	1.50	3.05	3.46	1.32	T.	27.11
1907	.15	.25	.48	.91	2.44	2.55	6.35	1.62	2.59	1.45	.16	2	20.95
1908	.08	.67	.18	.50	.78	3.45	1.52	1.61	.61	.99	2.72	.23	13.34
1909	.30	.35	2.15	.07	2.50	3.44	5.10	1.31	1.43	.68	3.77	.70	21.80
1910	.50	.25	T.	1.04	1.52	3.23	2	2.99	.14	T.	.15	T.	11.82
1911	T.	3.53	.89	.32	3.19	.61	1.84	1.68	.23	1.85	.95	1.66	16.75
1912	.28	3.04	.98	2.55	.56	4.07	1.76	3.49	1.34	.33	.29	.05	18.74
1913	.15	1.15	.50	1.21	2.30	3.12	4.97	.87	5.47	.23	1.19	2.42	23.58
1914	0	T.	T.	1.74	3.63	1.44	.56	.64	.15	1.48	T.	.06	9.70
Mean	.32	1.15	.93	2.07	2.40	3.16	3.01	1.88	1.94	1.07	.95	.76	19.64
Dalhart, Tex.:													
1908	T.	.85	.04	2.28	.53	2.83	4.11	1.08	.39	.29	.99	0	13.39
1909	T.	.28	.71	.18	1.70	5.10	1.27	.65	2.12	2.60	1.21	.15	15.97
1910	.20	.03	.12	1.51	2.96	4.04	2.48	3.28	.05	0	.07	.02	14.76
1911	0	.54	.43	.59	3.37	.28	3.65	1.87	.58	1.72	.25	1.28	14.56
1912	0	1.30	.38	2.56	2.37	3.36	1.68	2.64	1.98	.05	0	.03	16.35
1913	.06	.14	.02	.88	2.35	1.29	.85	1.50	1.45	.09	1.78	3.18	13.59
1914	.05	T.	T.	3.98	7.29	3.65	2.58	1.38	.32	3	0	.56	22.81
Mean	.04	.45	.24	1.71	2.94	2.94	2.37	1.77	.98	1.11	.61	.75	15.92
Amarillo, Tex.:													
1892	.42	.57	2.10	.21	2.70	1.49	1.85	1.93	.24	2.85	.16	1.08	15.60
1893	.09	2.03	T.	.16	2.19	2.03	2.05	2.67	5.27	.03	.28	.43	17.23
1894	.02	1.15	.05	[illegible]	1.30	3.59	1.82	3.41	2.41	.39	0	.82	15.81
1895	1.60	1.92	.16	1.31	1.78	6.84	2.83	3.87	.57	2.26	.81	.79	24.79
1896	.76	.41	.21	1.95	2.20	2.31	7.04	.63	2.45	3.09	.35	2.88	24.28
1897	2.26	.65	.47	1.08	4.44	2.32	2.16	2.71	.73	1.63	.08	.63	19.16
1898	.86	.82	.35	.98	3.52	4.81	3.88	4.03	.48	.41	.34	2.06	22.54
1899	.29	.07	.17	.23	3.12	4.45	6.96	.51	6.09	1.15	3.24	1.11	27.39
1900	.59	.47	.48	5.47	4.53	1.84	3.21	.83	5.25	1.58	.08	.07	24.40
1901	.03	.48	.02	4.90	5.99	.92	1.56	3.03	2.19	3.26	2	.04	24.42
1902	.04	T.	.74	1.83	9.14	2.01	1.45	2.42	.95	1.74	2.24	.55	23.11
1903	.12	2.93	.26	.90	1.79	2.83	3.38	4.67	.82	2.58	0	T.	20.28
1904	.16	.08	T.	.63	2.88	5.53	2.48	4.69	3.55	.44	.20	.69	21.33
1905	1	1.52	2.62	4.52	6.16	2.19	3.76	.63	3.08	.30	5.09	1.45	32.32
1906	.41	.51	.64	3.23	1.18	2.07	2.90	6.76	1.96	2.49	2.58	.19	24.92
1907	1.11	.24	.02	1.30	1.13	2.23	1.47	6.15	.97	1.64	.69	1.46	18.41
1908	.26	.72	T.	1.86	3.44	1.73	4.64	3.39	1.50	.37	.51	0	18.42
1909	.07	.28	1.08	.27	1.13	5.90	2.19	1.39	1.90	1.18	3.25	.54	19.18
1910	.05	.17	.41	.53	2.61	1.48	2.61	2.46	.05	.13	.19	T.	10.69
1911	.07	3.26	.50	3.90	6.74	.35	5.92	2.54	1.30	1.53	.55	1.14	27.80
1912	T.	1.85	.78	.82	1.62	2.31	2.50	1.51	2.28	.33	T.	.33	14.33
1913	.01	.41	.44	1.69	1.71	2.29	1.40	.47	5.60	.83	2.26	2.17	19.28
1914	T.	.01	.02	1.27	3.83	.65	1.90	2.52	1.10	3.98	0	.87	16.15
Mean	.44	.89	.50	1.73	3.27	2.70	3.04	2.75	2.21	1.49	1.08	.84	20.95

[1] T=Trace.

It will be noted that at each of the stations, from 40 to 45 per cent of the total precipitation falls during the growing season of the crops studied; that is, in the months of June, July, and August.

WIND VELOCITY.

Considered as a whole, the southern portion of the Great Plains has a high wind velocity. It is not, however, the high average velocity as much as the occasional high winds, which usually last only a short time, that must be considered as the injurious factor in crop production. The damage to crops in this region by wind may be accomplished either by soil blowing, by excessive transpiration from the leaf surface, or by direct loss of soil moisture by drying. Transpiration from the leaf surface is an uncontrollable factor in crop production and will not be further discussed. The wind reaches its maximum velocity during the months of March, April, and May, although there are occasional days throughout the entire year when the velocity is high. Wind velocity, in so far as its soil-blowing effect is concerned, does not readily lend itself to any form of scientific measurement, and data other than those gathered by general observations can not be given. The extent to which wind velocity may affect soil movement also depends largely upon the condition of the surface soil.

EVAPORATION.

The amount of evaporation from a free water surface during the growing season is very high in the southern portion of the Great Plains. This is due to a combination of high altitude, dry air, excessive wind, high temperatures, and long periods of drought. The seasonal evaporation for this area is about 55 inches, as compared with about 30 inches for the northern portion of the Great Plains. This relatively high evaporation doubtless accounts for some of the differences in crop yields. It is also one of the determining factors in the crop variety which can be successfully produced in this region.

The amount of evaporation from a free water surface should not be confused with the evaporation from the soil except that it may offer rather a close relation to the water lost from the first few inches of soil when the soil is thoroughly saturated. Considerable work is now being done at all of these stations to determine the rate and amount of water lost from the soil by evaporation, but this subject will not be considered here.

Table II gives the monthly and seasonal evaporation in inches from a free water surface at the level of the ground at the Garden City, Dalhart, and Amarillo stations for the years during which the experiments here reported have been conducted.

TABLE IV.—*Monthly and seasonal evaporation at Garden City, Kans., and at Dalhart and Amarillo, Tex., for the years stated.*

[Data in inches.]

Station and year.	Apr.	May.	June.	July.	Aug.	Sept.	Total.
Garden City, Kans.:							
1908	9.02	9.86	10.56	9.46	9.69	7.61	56.13
1909	6.57	9.10	8.76	9.80	9.88	7.46	51.56
1910	7.76	6.33	9.43	10.47	7.63	6.81	48.41
1911	7.10	9.72	11.85	10.25	10.24	8.86	58.02
1912	6.80	10.82	8.58	10.64	9.15	7.09	53.08
1913	2.81	8.23	9.51	14.15	12.90	6.93	54.51
1914	6.92	7.05	9.94	9.40	10.01	9.37	52.69
Mean	6.71	8.73	9.80	10.60	9.93	7.73	53.49
Dalhart, Tex.:							
1908	5.92	10.92	12.07	9.18	9.89	7.95	55.93
1909	8.53	9.90	10.89	11.69	10.57	7.84	59.40
1910	8.54	8.18	12.02	11.63	8.82	8.44	57.63
1911	7.56	9.90	12.37	9.71	10.90	8.77	59.21
1912	8.21	10.24	8.48	11.10	9.13	6.75	53.91
1913	7.69	10.06	8.71	12.70	10.77	6.34	56.27
1914	6.54	7.81	10.26	8.84	9.06	8.23	51.81
Mean	7.57	9.57	10.69	10.69	9.88	7.76	56.31
Amarillo, Tex.:							
1907	6.36	8.04	9.59	10.68	9.40	7.91	51.98
1908	7.31	9.28	10.38	8.07	8.57	6.77	50.38
1909	8.14	10.02	10.34	9.97	9.66	8.42	56.55
1910	8.50	8.03	12.00	12.18	8.80	9.10	58.61
1911	7.36	10.10	11.48	7.48	8.89	7.28	52.59
1912	7.05	9.90	8.99	10.95	9.49	6.49	52.87
1913	7.70	9.76	7.01	12.69	10.34	5.90	53.40
1914	6.70	6.74	10.12	8.75	8.93	8.04	49.28
Mean	7.39	8.98	9.99	10.10	9.26	7.49	53.21

HAIL.

The damage due to hail in the southern portion of the Great Plains is of minor importance. The hailstorms usually occur before the first of June. Fortunately, most of the profitable crops of this section can be seeded after this date. Furthermore, under favorable conditions, both the grain and forage sorghums have the ability to make a rapid recovery after being badly damaged by hail.

TEMPERATURE.

There is a wide range in the daily temperature of this region. This is especially noticeable during the early spring and late fall. The entire growing season is characterized by hot days and cool nights. This does not greatly affect the crops most commonly grown, however, but is doubtless one of the reasons why some crops, like corn and cotton, can not be more successfully produced.

SOIL.

For the purpose of this bulletin, the soil at the stations under study may be divided into two different types known as "tight land" and "loose land." The former varies from a sandy clay to a light sandy loam, and the latter varies from a light sandy loam to almost pure

sand. There is very little difference in the productivity of these two types of soil, but they demand different treatment to produce the best results.

Generally speaking, the sandy soils give more trouble from blowing and drifting than do the heavier soils. On the other hand, they have the advantage of being more receptive of rainfall. On the sandy soils tillage implements which do not pulverize the surface but leave it in a rough condition should be used. At Garden City and Dalhart much difficulty has been experienced in handling this class of soils so as to prevent blowing. The soil at Amarillo is heavy, and little difficulty is there experienced from this source.

EXPERIMENTAL WORK.

Work was started at the Garden City station and the first crop produced in 1907. The Dalhart station was started in 1907 and the first crop was produced in 1908. The first crop was produced at Amarillo in 1906. In the fall of 1909 this station was moved to a new location and the first crop at the new location was produced in 1910. In preparing the tables covering these studies the yield of the crop for the first year at each of the stations has not been used, because the land was uniform in its preparation. The yield of the 1910 crop at Amarillo has not been included on account of the station being moved.

At all of these stations an attempt has been made to produce all of the farm crops that could reasonably be expected to grow successfully in this region. Not only has this practice been rigidly adhered to, but an effort has also been made to grow these crops under as many different methods of tillage as would be met with in ordinary farm practice. In other words, the range of preparation and cultivation has been from the extensive to the intensive system of farming.

SMALL GRAIN.

Spring wheat, winter wheat, oats, and barley will be considered in this study under this heading. The greatest disadvantages attending the growth of small grains in the southern portion of the Great Plains are the unfavorable climatic conditions prior to and immediately after seeding. The precipitation table shows that the rainfall from September 1 to May 1 is usually very light. The soil is very dry at the time for seeding small-grain crops. This is especially true if a crop has been grown on the land the previous summer. It is difficult to secure a stand of small grain when seeded under these conditions. As a result of the scant rainfall and the dry soil at seeding time the growth of the young plants is so retarded that they do not make a sufficient growth to protect themselves from soil

blowing, which is most severe during March and April. When soil blowing starts on a field of small grain it is almost impossible to stop it without some heavy cultivation, which is impossible without destroying part of the crop. There are other and minor factors influencing the growing of small grains which are not discussed in this bulletin. There will undoubtedly be occasional seasons of heavy rainfall, when a crop of small grain might be successfully grown, but as a general practice the growing of small grains in this section can not be too severely condemned.

The results of the experimental work in the production of wheat, oats, and barley in the Great Plains by the Office of Dry-Land Agriculture have been published in separate bulletins (Nos. 214, 218, and 222, respectively) in the present series.

SORGHUMS.

Experimental work with the saccharine sorghums has been chiefly along the lines of variety and rate-of-seeding tests. On the whole, the yields have been very satisfactory. Very little work has been done in studying methods of preparation of the land for these crops. It is probable, however, that their relative response to differences in cultural methods is substantially the same as that of kafir and milo.

PRESENTATION OF RESULTS.

Tables IV to XII, inclusive, present the results of experimental work with corn, milo, and kafir at the Garden City, Dalhart, and Amarillo stations. These tables give for each station the yields of grain and stover each year, the average yield of each for the whole period of years under study, the value of the crop, the cost of producing it, and the resulting profit or loss.

In order to compare the relative profitableness of different methods it has been necessary to assign values to the products and to determine the relative costs of producing the crops by the different methods under study.

An accurate record of all the farm operations performed by the various methods under trial has been kept at each station. The average of these for the three stations is presented in Table III. It is recognized that this table does not exactly represent the requirements of any one of the stations, but the average seems to afford a fair basis of comparison. From estimates and determinations of an average day's work the cost of each cultural operation has been computed and is given in the table. In arriving at these items of cost a wage scale of $2 a day for a man and $1 a day for a horse has been allowed. Fifteen cents per acre for wear and tear on the binder is added to the labor cost of harvesting. An allowance of 8 per cent

on a valuation of $20 per acre is added for taxes and interest on the land.

To these items must finally be added a charge of 22 cents per acre for seed in the case of corn, as shown in Table III, and 17 cents per acre for kafir or milo seed.

TABLE III.—*Comparative cost per acre of producing corn*[1] *by different methods at Garden City, Kans., and Dalhart and Amarillo, Tex.*

Method of preparation.	Number of operations.				Cost of preparation.	Cost per acre.				Interest and taxes.	Total cost of production.		
	Plowing.	Harrowing.	Disking.	Subsoiling.		Seed.	Planting.	Cultivating.	Harvesting.		In dollars.	In stover, at $4 per ton.	In grain at 40 cents per bushel.
Listed	......	1	1	......	$0.92	$0.22	$0.60	$1.14	$1.50	$1.60	5.98	1.50	15.0
Spring plowed	1	1.4	.6	......	2.40	.22	.25	1.14	1.50	1.60	7.11	1.78	17.8
Fall plowed	1	1.4	1.1	......	2.78	.22	.25	1.14	1.50	1.60	7.49	1.87	18.7
Subsoiled	1	1.4	1.1	0.5	3.47	.22	.25	1.14	1.50	1.60	8.18	2.05	20.5
Summer tilled	1.4	8.3	3	......	6.05	.22	.25	1.14	1.50	3.20	12.36	3.09	30.9

[1] Based on three cultivations. With the reduction of 5 cents per acre in the cost of seed, the same figures are used for both kafir and milo.

To determine the value of the crop is even more difficult. The farm value of corn in the Great Plains on December 1 for the 10 years ending with 1914 has been 51 cents per bushel. The writers have used in this study a valuation for each of the three crops of 40 cents per bushel in the shock. This allows 11 cents per bushel to complete the harvesting. In the territory under consideration, these crops are fed locally and a large part of them without husking or thrashing.

The average price of hay for the same territory during the same time has been $6.22 per ton. An arbitrary value of $4 per ton is assigned to the stover or fodder from each of the crops. This probably is an overvaluation of milo, and possibly of corn, in comparison with kafir. The corn roughage is of a much better quality than in better corn sections. In many cases it contained some grain, but not enough to warrant husking. In some instances, as is shown in detail in the tables, the only production from milo and kafir has been that of roughage. This is an indication of generally unfavorable conditions and scarcity of feed. In such years any feed is comparatively valuable, as it makes it possible to carry over stock without loss or a reduction in numbers so serious as to unbalance the farming system.

For the sake of uniformity the term "stover" is used in all the tables.

RESULTS WITH CORN AT INDIVIDUAL STATIONS.

The results with corn at these stations have been presented in a bulletin entitled "Corn in the Great Plains Area: Relation of Cul-

tural Methods to Production." As this bulletin will have a somewhat different circulation from that one, and as it seems desirable to show the results with corn in comparison with those of the other two important feed crops, milo and kafir, they are here presented.

CORN AT GARDEN CITY.

With the exception of a very light grain yield in 1914, which was included in the stover weight, corn has not matured grain at Garden City; therefore it can be considered only as a fodder crop. A study of Table IV shows little difference in the yields obtained by spring and fall plowing. A slight difference does exist between the yields obtained where corn follows corn and where corn is grown after small grains. The difference is in favor of the first-named crop sequence, indicating that corn leaves the land in better condition for a succeeding crop than small grain does. Subsoiling has increased the yield over listing and fall and spring plowing, but the increased yield has been just sufficient to balance the extra expense incurred in using this method of seed-bed preparation. Listing gives the lowest average yield of fodder, but since this method is the least expensive it has been productive of the smallest loss. Corn following summer tillage has produced the highest yields, but as this is the most expensive method under trial it has resulted in the greatest loss. As calculated in Table IV, corn at this station has not been produced at a profit by any method under trial.

TABLE IV.—*Summary of yields and digest of the cost of production of corn by different tillage methods and crop sequences at Garden City, Kans., 1909 to 1914, inclusive.*

Yields, values, etc. (average per acre).	Fall plowed.				Spring plowed.				Subsoiled after corn (1 plat).		Listed after corn (2 plats).		Summer tilled (1 plat).	
	After corn (1 plat).		After small grain (11 plats).		After corn (1 plat).		After small grain (11 plats).							
	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.
Yield for the year:	Bus.	Lbs.	Bus.	Lbs.	Bus.	Lbs.	Bus.	Lbs.	Bus.	Lbs.	Bus.	Lbs.	Bus.	Lbs.
1909	......	......	0	2,972	......	......	0	3,446	......	......	0	2,180	......	......
1910	......	......	......	......	......	......	......	......	......	......	......	......	......	......
1911	0	1,400	0	934	0	1,100	0	1,269	0	750	0	695	0	4,000
1912	0	4,620	0	4,498	0	5,580	0	3,935	0	4,500	0	5,570	0	5,700
1913	[1] H.	H.	H.	H.	H.	H.	H.	H.	H.	H.	H.	H.	H.	H.
1914 [2]	0	3,040	0	2,668	0	2,460	0	2,100	0	4,840	0	2,830	0	4,320
Average	0	3,020	0	2,768	0	3,047	0	2,688	0	3,363	0	2,819	0	4,700
Crop value, cost, etc.:														
Value	......	$6.04	......	$5.54	......	$6.09	......	$5.38	......	$6.73	......	$5.64	......	$9.40
Cost	$7.49		$7.49		$7.11		$7.11		$8.18		$5.98		$12.36	
Loss	−1.45		−1.95		−1.02		−1.73		−1.45		− .34		−2.96	

[1] H=Destroyed by hail. [2] Very small yield of grain; weight included with stover.

CORN AT DALHART.

Six crops of corn have been grown at the Dalhart station. In three of the years under study grain was produced, while in the other three years nothing but stover was produced. The best yield was obtained in 1914, when optimum seasonal conditions for the production of this crop prevailed. Listing has been productive of the highest average yield of grain, but it is thought that this may be due to the fact that the listed plat occupies such a position on the farm that it sometimes receives considerable run-off. Because of the low cost of this method of preparation it gives the greatest profit. Summer tillage is the most costly method of seed-bed preparation: consequently it returns rather a low profit, although it insures a good yield of fodder every year. The difference between the average yields by spring and fall plowing is very slight.

TABLE V.—*Summary of yields and digest of the cost of production of corn by different tillage methods and crop sequences at Dalhart, Tex., 1909 to 1914, inclusive.*

Yields, values, etc. (average per acre).	Fall plowed.				Spring plowed.				Listed after corn (1 plat).		Summer tilled (1 plat).	
	After corn (1 plat).		After small grain (12 plats).		After corn (1 plat).		After small grain (7 plats).					
	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.
Yield for the year:	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*
1909	0	1,000	0	946	0	700	0	1,014	0	2,250	0	3,400
1910	8.6	3,160	9.2	2,947	15.1	3,610	15.3	2,914	25.6	3,340	25.6	4,110
1911	0	4,000	0	2,771	0	4,000	0	2,708	0	2,350	0	3,000
1912	7.4	2,250	14.1	2,779	10.5	2,200	9.7	2,751	21.0	3,100	23.0	3,300
1913	0	2,000	0	2,405	0	2,150	0	1,037	0	1,750	0	6,150
1914	35.6	3,855	20.3	3,566	31.5	3,690	17.0	3,255	25.1	2,740	30.8	3,440
Average	8.6	2,711	7.3	2,569	9.5	2,725	7.0	2,280	14.0	2,588	13.7	3,900
Crop value, cost, etc.:												
Value	$3.44	$5.42	$2.92	$5.14	$3.80	$5.45	$2.80	$4.56	$5.60	$5.18	$5.48	$7.80
Total value	$8.86		$8.06		$9.25		$7.36		$10.78		$13.28	
Cost	7.49		7.49		7.11		7.11		5.98		12.36	
Profit	1.37		.57		2.14		.25		4.80		.92	

CORN AT AMARILLO.

Seven crops of corn have been grown at Amarillo, Tex., and, although only one complete grain failure is recorded, the yields of four years were so low that husking would have been impracticable in farm practice. The 1908 yields varied from 14.7 to 27.6 bushels per acre. If such yields could be obtained consistently, the growing of corn in this section would be justified. The average yields, however, are not sufficient to cover the cost of production. All methods

have produced fodder each year, but in only one year has there been a creditable production of grain.

The differences in the yield from different methods have been comparatively small. Summer-tilled land shows a small increase in the yield of both grain and stover over all other methods. Fall plowing has proved a somewhat better preparation than either spring plowing or listing. Subsoiling has failed to increase yields over fall plowing.

Listing shows a small profit of 67 cents per acre. All other methods show losses ranging from 19 cents per acre by fall plowing after corn to $2.85 on summer-tilled land.

TABLE VI.—*Summary of yields and digest of the cost of production of corn by different tillage methods and crop sequences at Amarillo, Tex., 1907 to 1914, inclusive.*

Yields, values, etc. (average per acre).	Fall plowed.				Spring plowed.				Subsoiled after corn (1 plat).		Listed after corn (2 plats).		Summer tilled (1 plat).	
	After corn. (1 plat).		After small grain (11 plats).		After corn (1 plat).		After small grain (3 plats).							
	Grain.	Stover.	Grain.	Stover.	Grain.	Stover	Grain	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.
Yields for the year:	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*
1907	1.4	3,270	2.3	2,997	3.1	3,280	2.1	3,010	1.1	3.490	2.2	2,935	5.7	3,710
1908	22.9	4,580	19.8	3,107	20.3	3,300	14.7	2,863	25.7	3,810	24.7	2,390	27.6	3,700
1909	2.7	1,310	0	1,596	.6	560	0	1,383	1.7	990	5.4	1,043	6.4	1,890
1911	9.2	2,075	8.9	2,145	8.1	1,945	9.5	1,960	7.1	1,720	7.8	1,998	9.3	2,050
1912	.7	1,680	1.7	1,848	2.6	2,160	1.1	1,829	1.0	2,080	1.7	2,015	3.3	2,840
1913	0	380	0	773	0	700	0	383	0	430	0	225	0	1,750
1914	3.6	4,140	5.1	3,641	1.1	1,500	2.6	2,733	5.1	4,850	7.0	2,870	8.0	5,320
Crop value, cost, etc.: Average	5.8	2,491	5.4	2,301	5.1	1,921	4.3	2,023	6.0	2,481	7.0	1,925	8.6	3,037
Value	$2.32	$4.98	$2.16	$4.60	$2.04	$3.84	$1.72	$4.05	$2.40	$4.96	$2.80	$3.85	$3.44	$6.07
Total value	$7.30		$6.74		$5.88		$5.77		$7.36		$6.65		$9.51	
Cost	7.49		7.49		7.11		7.11		8.18		5.98		12.36	
Profit or loss	− .19		− .75		−1.23		−1.34		− .82		.67		−2.85	

RESULTS WITH MILO AND KAFIR AT INDIVIDUAL STATIONS.

Milo is undoubtedly the leading grain crop grown in this section and has given surer and better grain yields, on the average, than any other crop grown at the stations included in this study. Two types of this crop are commonly grown, namely, Standard and Dwarf. The Standard type grows a stalk averaging about 4½ feet in height, depending upon seasonal conditions, while the Dwarf probably will not average over 3 feet. Differences in yield due to seasonal conditions so far overshadow any differences in type that it is almost impossible to draw any definite conclusions as to just

which of the two types gives the better yield. It is probable, however, that the average yield for a series of years would be in favor of the Dwarf type. If the grain is to be headed and the stalks left in the field, it would probably be advisable to plant the Dwarf, since it is not so high and can be more easily headed with a header or by hand. The Standard is more easily handled with a row binder, and where the stalks are to be saved and fed in the bundle or the crop used for silage this type should be planted.

Two varieties of kafir are also universally grown. These are the Standard and the Dwarf, and what has been said of the different types of milo may also be said of these kafir varieties. Kafir differs from milo in that it requires a longer season to mature and is frequently injured by frost, as will be seen by referring to the tables presented in connection with these studies.

Milo has usually given the highest grain yield, while kafir has given uniformly higher yields of fodder. Not only does kafir give a larger yield of fodder than milo, but the quality is far superior. This is especially true if an attempt is made to harvest the milo crop for both seed and fodder. The reason for this is that the milo stalk ripens before the head and there are very few leaves left on a hard, woody stalk at the time of harvest for grain. With kafir the ripening is just the reverse of milo; that is, the head ripens before the stalk, which makes it possible to harvest a grain crop when grain is produced and at the same time a fodder crop of good quality.

MILO AT GARDEN CITY.

Six crops of milo have been grown at Garden City, Kans. Since three of these failed to produce grain, the average grain yield is very low. Yields of milo grown after summer tillage are not included in the experiments here reported. The work has been rearranged and extended to include it and a wide range of methods of seed-bed preparation. Of the methods here reported there is not sufficient difference in the average yields to indicate the great superiority of any one over the others. The lowest yield of both grain and stover has been on spring-plowed land continuously cropped to milo. The highest yield has been from fall plowing after small grain. The former method has resulted in an average loss of 83 cents per acre, while the latter has given a profit of $2.07 per acre. Considering the value of both grain and stover, only two of the six crops on fall-plowed and on listed land have been produced at a loss, while only one crop on spring-plowed land has returned a profit.

It will be seen that at this station milo stover at a valuation of $4 per ton has returned a greater value than the grain when priced at 40 cents a bushel. At the other stations the opposite has been true in

nearly every case. This is an important consideration in studying milo yields, as the crop is usually grown for the grain.

TABLE VII.—*Summary of yields and digest of the cost of production of milo by different tillage methods and crop sequences at Garden City, Kans., 1909 to 1914, inclusive.*

Yields, values, etc. (average per acre).	Fall plowed. After milo (1 plat).		Fall plowed. After small grain (2 plats).		Spring plowed, after milo (1 plat).		Listed, after milo (1 plat).	
	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.
Yields for the year:	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*
1909	0	3,950	0	5,345	0	3,370	0	3,830
1910	14	2,150	21.8	3,275	7.6	1,940	12.4	2,380
1911	0	760	0	360	0	380	0	0
1912	30.5	3,120	27.1	3,010	25	2,750	29.1	3,775
1913	0	260	0	770	0	620	0	300
1914	8.5	2,670	13.9	3,175	4.8	2,180	11.2	1,930
Average	8.8	2,152	10.5	2,656	6.2	1,873	8.8	2,036
Crop value, cost, etc.:								
Value	$3.52	$4.30	$4.20	$5.31	$2.48	$3.75	$3.52	$4.07
Total value	$7.82		$9.51		$6.23		$7.52	
Cost	7.44		7.44		7.06		5.93	
Profit or loss	.38		2.07		— .83		1.59	

MILO AT DALHART.

Milo has given higher average yields at Dalhart, Tex., than at any of the other stations, and there is a greater range in the average profits per acre from different methods. The grain yields vary from a complete failure to 69 bushels per acre. Records for six years are available from this station. In all but two years milo has been grown at a profit by all methods under trial. Milo following summer tillage has been profitable in all years except one. This fact, combined with the high average yield of both grain and stover and the net profit of $14.21 per acre that it returns, makes it a method of great importance for the Dalhart region. The crop was harvested in bulk and converted into ensilage in 1913, but the summer-tilled plat produced an estimated yield of at least 600 pounds of grain per acre. The yields obtained show that summer tillage has insured a grain yield in dry years, and, except in one year, has increased the yield over that from other methods.

The listing method returns the next highest profits per acre. The plat devoted to this method occupies a low place on the farm and may catch run-off water in sufficient quantity to increase the yields. The low cost of preparation by this method is a point in its favor.

The low yields obtained from milo following small grain by fall plowing have been due more to imperfect stands than to any other

known factor, and it is hardly fair to compare these yields with those secured by other methods.

A study of the yields by fall and spring plowing where milo follows milo shows no appreciable difference in the value of these two methods. Both methods have given good profits.

TABLE VIII.—*Summary of yields and digest of the cost of production of milo by different tillage methods and crop sequences at Dalhart, Tex., 1909 to 1914, inclusive.*

Yields, values, etc. (average per acre).	Fall plowed.				Spring plowed after milo (1 plat).		Listed after milo (1 plat).		Summer tilled (1 plat).	
	After milo (1 plat).		After small grain (2 plats).							
	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.
Yield for the year:	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*
1909	2.8	1,660	3.8	3,000	3.3	3,990	3.8	1,590	14.7	4,980
1910	26.6	6,660	21.2	6,945	26.4	6,950	50.4	8,380	69.0	11,520
1911	19.1	4,270	0	755	5.9	2,000	23.6	3,330	27.8	3,530
1912	28.6	4,650	33.1	2,965	39.7	4,610	22.4	2,770	52.4	6,500
1913	0	1,750	0	2,275	0	1,800	0	1,250	[1] 10.3	3,600
1914	55.5	4,980	(2)	(2)	51.7	5,040	48.4	4,130	45.3	5,500
Average	22.1	3,995	11.6	3,188	21.2	4,065	24.8	3,575	36.6	5,938
Crop value, cost, etc.:										
Value	$8.84	$7.99	$4.64	$6.38	$8.48	$8.13	$9.92	$7.15	$14.64	$11.88
Total value	$16.83		$11.02		$16.61		$17.07		$26.52	
Cost	7.44		7.44		7.06		5.93		12.31	
Profit	9.39		3.58		9.55		11.14		14.21	

[1] Estimated yield; harvested in bulk for ensilage.
[2] Discontinued in 1914.

MILO AT AMARILLO.

Seven crops of milo have been grown at Amarillo, Tex., and grain yields were secured from six of them. Milo after small grain on fall plowing has given better average results than any other tillage method used at this station. General observation as to yields indicates that crop sequence has less influence than other factors. The yields of milo grown on fall-plowed land following small grain do not greatly exceed those obtained from different methods on land continuously cropped to milo. In fact, with the exception of summer tillage, there is little variation among the average yields by all the different methods under trial. Listing has produced the smallest quantity of stover, but this is of no great importance, as high grain yields are preferred to high stover yields. Four years out of the six milo after milo by spring plowing has given heavier yields than milo after milo by fall plowing, and one year out of three it has exceeded the yield on summer-tilled land. It is hardly fair to compare the practice of summer tillage at this station with other tillage methods, as it has been under trial only three years. In 1913, when because of the extreme drought all other methods failed even to set

heads, milo on summer-tilled land made a yield of grain, which was destroyed by birds, estimated at 10 to 15 bushels to the acre.

TABLE IX.—*Summary of yields and digest of the cost of production of milo by different tillage methods and crop sequences at Amarillo, Tex., 1907 to 1914, inclusive.*

Yields, values, etc. (average per acre).	Fall plowed.				Spring plowed after milo (1 plat).		Listed after milo (2 plats).[1]		Summer tilled (1 plat).	
	After milo (1 plat).		After small grain (2 plats).							
	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.
Yields for the year:	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*
1907	21.6	4,170	27.9	4,175	18.1	2,560	31.7	3,810	....	....
1908	32.8	3,280	46.5	4,590	40.3	3,500	37.9	3,250	....	....
1909	.9	1,740	10.1	2,962	2.6	2,045	10.9	2,318	....	....
1910[2]	....	....	....	....	....	....	....	....	....	....
1911	31.4	4,350	26.5	3,698	35.4	3,500	17.4	2,010	....	....
1912	27.4	2,760	26.7	3,050	33.5	3,290	25.4	2,515	24.1	3,570
1913	0	130	0	715	0	440	0	410	0	2,000
1914	29.0	4,010	24.5	3,810	17.6	3,050	23.3	1,880	27.	4,820
Average	20.4	2,920	23.2	3,286	21.1	2,626	20.9	2,313	17.1	3,463
Crop value, cost, etc.: Value	8.16	5.84	9.28	6.57	8.44	5.25	8.36	4.63	6.84	6.93
Total value	$14.00		$15.85		$13.69		$12.99		$13.77	
Cost	7.44		7.44		7.06		5.93		12.31	
Profit	6.56		8.41		6.63		7.06		1.46	

[1] Only one listed plat used until 1912. [2] Station site changed in 1910; yields not used.

A comparison of the yields secured at Amarillo and Dalhart is of interest, because the two stations are only 90 miles apart, but they are located on altogether different types of soil. The Dalhart station has an average annual rainfall of 15.92 inches and is located on a sandy-loam soil, while the Amarillo station has a yearly precipitation of 20.95 inches and is located on a heavy, silty clay loam. Judging from the average rainfall, the yields at Amarillo should be greater than at Dalhart. The records show, however, that better average yields have been produced at Dalhart. This probably is due to the ability of the sandy soil at Dalhart to absorb a larger percentage of the annual rainfall.

KAFIR AT GARDEN CITY.

Kafir has been grown for six consecutive years at Garden City, Kans. The first crop was produced in 1909. With the exception of the year 1914, four different methods of seed-bed preparation and cultivation have been under study. In 1914 the growth of kafir after small grain was discontinued because of the repeated failures of the small-grain crop. During the six years that kafir has been grown at this station it has not produced a grain yield of any value except in 1912, when all methods gave good yields. The best yield was

27.8 bushels per acre on fall-plowed land following small grain. Kafir following small grain has, on the average, given slightly better yields of both grain and fodder than it has following kafir. These higher yields have doubtless been due to the repeated failure of the small-grain crop, which has left the ground partly summer tilled. There has been very little difference in the average grain yield by the different methods under study. From no method has this average yield been sufficient to cover the cost of its production. All methods have produced four good crops of forage. The average yield of fodder after fall plowing is above the average of any other method. The next highest yield has been after fall plowing following kafir.

Without exception the value of the forage has exceeded the value of the grain produced under all methods studied. Kafir after kafir on spring-plowed land has shown the lowest margin of profit, viz, 64 cents per acre. The greatest net profit per acre has been secured by growing kafir after small grain on fall-plowed land. The profit by this method is $3.78 per acre. The margin of profit from all methods has been small and, on the average, much lower than at Dalhart or Amarillo.

TABLE X.—*Summary of yields and digest of the cost of production of kafir by different tillage methods and crop sequences at Garden City, Kans., 1909 to 1914, inclusive.*

Yields, values, etc. (average per acre).	Fall plowed.				Spring plowed after kafir (1 plat).		Listed after kafir (1 plat).	
	After kafir (1 plat).		After small grain (2 plats).					
	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.
Yields for the year:	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*
1909	0	5,260	0	5,780	0	4,310	0	4,400
1910	5.0	3,880	9.6	6,800	2.2	3,550	2.7	3,820
1911	0	680	0	1,390	0	580	0	580
1912	27.8	5,970	25.1	5,745	22.5	5,400	20.6	5,805
1913	0	440	0	1,430	0	680	0	300
1914	6.7	3,340	(1)	(1)	3.7	2,940	3.8	2,750
Average	6.6	3,262	6.9	4,229	4.7	2,910	4.5	2,943
Crop value, cost, etc.:								
Value	$2.64	$6.52	$2.76	$8.46	$1.88	$5.82	$1.80	$5.89
Total value	$9.16		$11.22		$7.70		$7.69	
Cost	7.44		7.44		7.06		5.93	
Profit	1.72		3.78		.64		1.76	

[1] Discontinued in 1914.

A rotation of small grain and kafir is impracticable on account of the failure of small grain. Summer tillage should, therefore, be given a thorough trial, as it may prove to be the most profitable method. Experiments have been started to determine the most practical application of summer tillage for the growing of kafir.

KAFIR AT DALHART.

Kafir has been grown at Dalhart, Tex., for six years. During this time five different methods of seed-bed preparation and cultivation have been under study. Kafir after small grain on fall-plowed land was discontinued in 1914, on account of the impracticability of growing small grain. The results obtained during this study have on the whole been very satisfactory. The yields, and consequently the profits, obtained here are higher than at the other stations under study. There is also a wider range in the results obtained with the different cultural methods used, which would indicate that cultivation here is of more importance than at Garden City, Kans., or at Amarillo, Tex. The largest average net profit obtained was from the crop grown on land summer tilled the preceding year, amounting to $20.11 per acre. The method showing the least profit is that of fall plowing following small grain. The profit by this method was only $2.90, which is considerably below the average of the other methods used.

It is possible that the low profits shown by this method are due to the difficulty of securing a stand and to the fact that the small grains leave the soil very dry. Listing after kafir has given a net yield of $12.04 per acre, which is considerably higher than by any other method except summer tillage. Kafir after kafir on fall-plowed land has given an increased profit of $1.43 per acre over kafir following kafir on spring-plowed land.

After both listing and summer tillage the value of the grain crop alone has been sufficient to pay the cost of production. Under all methods the value of the forage has exceeded that of the grain.

TABLE XI.—*Summary of yields and digest of the cost of production of kafir by different tillage methods and crop sequences at Dalhart, Tex., 1909 to 1914, inclusive.*

Yields, values, etc. (average per acre).	Fall plowed.				Spring plowed after kafir (1 plat).		Listed after kafir (1 plat).		Summer tilled (1 plat).	
	After kafir (1 plat).		After small grain (2 plats).							
	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.
Yields for the year:	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*
1909	0	4,020	0	2,550	0	6,250	0	5,500	0	9,310
1910	30	10,140	17.9	9,075	18.7	8,420	55	12,270	75.5	18,310
1911	9.3	2,890	0	1,530	0	1,550	19.2	5,900	22.5	10,600
1912	0	5,500	5.5	4,625	0	6,000	9.7	3,950	29.8	9,500
1913	0	1,800	0	3,370	0	2,400	0	750	20.8	6,000
1914	44	7,760	([1])	([1])	39.2	7,100	17.3	5,260	37.8	6,230
Average	13.9	5,352	4.7	4,230	9.7	5,287	16.9	5,605	31.1	9,992
Crop value, cost, etc.: Value	$5.56	$10.70	$1.88	$8.46	$3.88	$10.57	$6.76	$11.21	$12.44	$19.98
Total value	$16.26		$10.34		$14.45		$17.97		$32.42	
Cost	7.44		7.44		7.06		5.93		12.31	
Profit	8.82		2.90		7.39		12.04		20.11	

[1] Discontinued in 1914.

KAFIR AT AMARILLO.

The results of seven years with kafir at Amarillo, Tex., are available. During this time only two complete grain failures have been recorded. While the net profits shown at Amarillo are not as large on the average as those obtained at Dalhart, Tex., they are considerably above those at Garden City, Kans. Kafir after summer tillage is the only method that shows a loss, but, as this method has been carried on for only three years, it is possible that this loss does not represent what might reasonably be expected by this method if it were tested for a longer time. The value of kafir following kafir on fall-plowed land exceeds that of kafir after kafir on spring-plowed land by $1.26 per acre. The largest profit by any method used has been obtained with kafir after small grain. For the seven years under study this method shows an average profit of $8.21 per acre.

TABLE XII.—*Summary of yields and digest of the cost of production of kafir by different tillage methods and crop sequences at Amarillo, Tex., 1907 to 1914, inclusive.*

Yields, values, etc. (average per acre).	Fall plowed.				Spring plowed after kafir (1 plat).		Listed after kafir (2 plats).[1]		Summer tilled. (1 plat).	
	After kafir (1 plat).		After small grain (2 plats).							
	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.
Yields for the year:	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*
1907	13.3	7,040	16.7	7,355	10.7	4,630	11.8	4,730		
1908	30.8	5,360	38.4	7,020	29.2	4,820	27.2	4,940		
1909	1.4	1,513	4.6	3,908	1.6	2,026	5.3	2,684		
1910[2]										
1911	21.8	7,280	18.9	8,310	21.7	4,350	8.0	1,500		
1912	0	5,660	0	6,020	0	6,870	0	5,215	0	6,160
1913	0	170	0	755	0	280	0	620	0	2,240
1914	12.0	3,940	6.9	4,340	8.3	3,790	12.5	2,760	7.0	4,880
Average	11.3	4,423	12.2	5,387	10.2	3,824	9.3	3,207	2.3	4,427
Crop value, cost, etc.: Value	$4.52	$8.85	$4.88	$10.77	$4.08	$7.65	$3.72	$6.41	$0.92	$8.85
Total value	$13.37		$15.65		$11.73		$10.13		$9.77	
Cost	7.44		7.44		7.06		5.93		12.31	
Profit or loss	5.93		8.21		4.67		4.20		−2.54	

[1] Only one plat used until 1912. [2] Station site changed in 1910; yields not used.

GENERAL DISCUSSION.

With the exception of the rainfall, which is less at Dalhart, Tex., than at Garden City, Kans., and Amarillo, Tex., the climatic conditions at the three stations under study are very similar. The soils of the three stations are of different types, but they are fairly representative of the more important agricultural types of soil to be found in the southern Great Plains area.

Experimental work was started one year earlier at Amarillo than at the other stations. Aside from this it has been carried on during the same years at each of the stations.

Summer tillage for milo and kafir has only recently been put under trial at Garden City. With this exception the same cultural methods have been used at each place. Small grains in this area have given generally unsatisfactory returns, although they have been much better at Amarillo than at either of the other two stations.

Saccharine sorghums have proved well adapted to conditions in the southern Great Plains area and usually have given good yields. The same cultural work has not been done with them as with the other crops. In general they may be expected to show about the same response to cultural conditions as is shown by the grain sorghums, for which results are here reported.

The results of this work show that corn can be depended upon to produce good crops of feed in this section. It does not, however, produce as big a tonnage of feed as kafir and is not as reliable as either kafir or milo in the production of grain. In trials covering six years at Garden City it has failed to produce a grain crop by any method. At Dalhart it has produced good crops of grain in three of the six years that it has been under trial. At Amarillo it has made but one creditable grain crop in seven years. Because of its comparatively poorer adaptation to conditions, it does not show relatively as great a response to cultural practices as does either kafir or milo.

Both milo and kafir have given higher average yields than corn at all of the stations. They have also been safer crops, having made crops of grain in some years when corn did not. They have also been more responsive to cultural operations, thus proving their better adaptation to conditions. On the sandy lands of this area corn makes a better showing in comparison with these crops than it does on the heavy, "tight lands," on which corn has little place in this section. When a comparison is made between milo and kafir it is seen that milo has given the better yields of grain and that kafir has given the better yields of roughage. Kafir, however, has shown a somewhat greater response to methods that, like summer tillage, increase the yields. When equal values are assigned to the grain and to the roughage from each of the crops, the total return is generally about the same from each. At Garden City the grain crop alone has not been sufficient to pay for the cost of production. At Dalhart both crops have produced sufficient grain by all methods to pay a profit. At Amarillo milo has returned a profit from the grain alone by some methods. The crop of kafir grain at Amarillo was not sufficient by any method to pay the cost of producing the crop.

When a value, believed to be a conservative one, is assigned to the fodder, both crops show a profit from nearly all methods under trial at all the stations. The only two exceptions are milo following milo by spring plowing at Garden City and kafir following summer tillage at Amarillo, where the summer tillage method has been on trial for only three years, all of which have been relatively unfavorable.

The most important results of the investigations, of which this is a partial report, are the demonstrations that this region is not adapted to the successful growth of small-grain crops, but that it is well adapted to forage crops and to certain types of grain sorghums when proper methods of tillage and crop sequence are practiced. This means that this region is undoubtedly destined again to become an important stock-producing section. It yet remains to be determined what classes of live-stock enterprises offer the greatest opportunities to the small farmers who have taken the place of the stockmen who formerly conducted an extensive and profitable business on the open ranges. It is certain that live stock of some kind must be grown to consume the forage and grain crops which can and will be grown in this region in enormously increasing quantities as its agricultural possibilities become better understood.

Although these investigations have so far demonstrated that but few crops have proved successful when grown by certain methods, it must not be understood that the limit has been reached either in crops or methods. On the contrary, these experiments tend to show that other crops and other methods may be developed which will produce even better results.

These investigations are being developed and modified to meet the requirements and the agricultural resources of the southern Great Plains area. The problem of utilizing the forage and grain crops for the production of live-stock products is now of vital importance, and with its solution the agricultural resources of this region will be materially increased.

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Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

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CONE BEETLES: INJURY TO SUGAR PINE AND WESTERN YELLOW PINE.

By JOHN M. MILLER,
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INTRODUCTION.

A class of damage which has been termed "blighted cones" occurs frequently in the seed crops of sugar pine throughout its range in California and Oregon and of western yellow pine in the Pacific coast and southern Rocky Mountain regions. This damage is distinguished by the dying of the immature cones soon after the starting of the second year's growth. The dead blighted cones, which are less than one-half the size of normal cones, are withered and faded to a reddish brown. The blighted sugar-pine cones fall to the ground during the first summer, whereas the blighted yellow-pine cones may adhere to the branches for several years.

INSECTS CAUSING DAMAGE.

The greater part of this damage[1] is caused by small scolytid beetles, which have been identified by Dr. A. D. Hopkins, of the Bureau of Entomology, as *Conophthorus* spp. The common name of "cone beetles" seems most appropriate for these insects, as their life history and the damage caused by them relate entirely to the cones of the host trees.

The adults are small, black, cylindrical beetles, from 3 to 4 mm. in length. The adult beetle bores a small tunnel through the axis of the cone, wherein the eggs are deposited. The larvæ, tiny white grubs from 3.5 to 4.5 mm. in length when full grown, feed upon the scales, seeds, and tissues of the withering cone.

The pupæ, which differ but little in size and color from the larvæ but possess the form of the adult, are formed within the same cone

[1] The caterpillars of certain cone moths also kill immature second-year yellow-pine cones, in such a way that the damage resembles the work of the cone beetle, but this damage may be readily recognized by the character of the attack. In the areas observed by the writer the cone worms cause less than 10 per cent of the blighted cones.

NOTE.—This bulletin is the result of field observations made in Oregon and California. It is suitable for distribution on the Pacific coast.

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in which the larvæ develop. The brood of new adults is also formed in the same cone, and here the adults overwinter.

THE SUGAR-PINE CONE BEETLE.

(*Conophthorus lambertianae* Hopk.)

SEASONAL HISTORY.

Frequent observations in the field were made during the season of 1914 in the vicinity of Ashland and Colestin, Oreg., and near Hilt, Cal., at elevations ranging from 3,800 to 4,200 feet. The area near Hilt was located where the timber-felling operations of the California Fruit Growers' Supply Association were conducted, where seed-bearing sugar-pine trees were felled daily.

The brood of adults which overwinters in the cones infested during the previous spring and summer emerges the following spring. Records kept during the seasons of 1913 and 1914 from various lots of rearing material show that the maximum spring emergence occurs during May (see Table I, p. 3). Emergence from material collected in the fall and kept over winter in the laboratory has varied anywhere from April 19 to June 13. Emergence from material collected in the spring which had overwintered in the field and then was kept outside in muslin rearing sacks occurred from May 8 to 31. Frequent examination of cones in the field also showed that the emergence is occurring during this period and that it reaches its maximum between May 15 and June 1. The first attacks noted upon the 1913–14 cones occurred between May 25 and June 1. Continued fresh attacks were observed until about June 20. The following description covers all observations regarding the method of attack and subsequent habits of the beetle:

Sugar-pine cones at the beginning of the second-year growth are about 2 to 2½ inches long and are attached to the limb by a stalk from 2 to 3 inches long. The parent adult beetle attacks the cone by boring into the stalk of the cone. The position of this initial entrance varies greatly; usually it is just above the base of the cone, but it may occur anywhere from the base of the cone to an inch or more above. The wound made by the beetle soon produces a flow of resin which gradually accumulates on the surface in the form of a small pitch tube (Pl. II, fig. 1). After boring into the center of the stalk the beetle turns toward the cone and continues to extend its tunnel straight outward through the axis of the cone (Pl. II, fig. 2). After it advances well into the heart of the cone the tunnel becomes the egg gallery, and single eggs are deposited at intervals in notches excavated along the sides of the burrow. The entire length of the egg gallery is packed with sawdust. Sawdust is also packed around the eggs in the egg notches (Pl. II, fig. 2).

The rate at which the egg gallery is advanced by the adult has not been definitely determined, as it is impossible to determine the

progress made by the adults without cutting the cone open, and when thus disturbed the adult at once ceases its work. However, it has been observed that the egg gallery has been extended entirely through the small cones within five to eight days after attack. For the same reason the period of incubation of the eggs within the cone has not been definitely determined. In cones cut open, eggs that had apparently just been deposited incubated in from two to four days.

One pair of parent beetles are found in each of these egg galleries. A series of specimens collected from individual cones was submitted to Dr. A. D. Hopkins, and from his determination of sex it was found that one male and one female beetle occupy each egg gallery. As a rule but one pair of beetles attack a single cone, but in some instances three pairs of beetles have been found advancing as many egg galleries in the same cone. The sex of the parent which makes the initial attack on the cone and begins the excavation of the egg gallery has not been determined.

The immediate effect of this attack on the cone is to check all further growth. Eventually the infested cone withers, then becomes dry and hard, but for a period of time it hangs on the tree in a semimoist and souring condition. It is during this period that the eggs of the beetle incubate and the young larvæ develop. The condition of the cone may be compared to that of the cambium of a pine which has been infested by Dendroctonus, and is in a fading or dying condition while the larvæ of the new broods of beetles are developing.

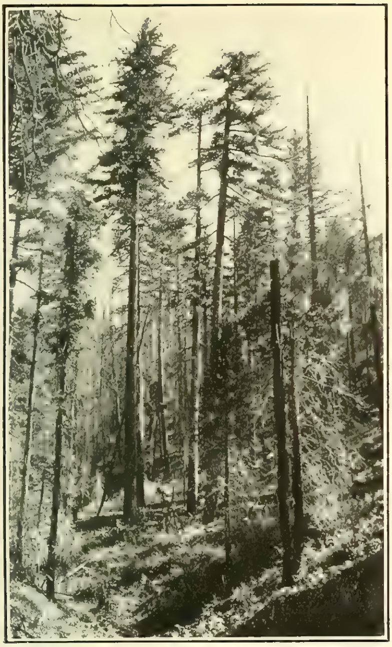
TABLE I.—*Emergence record of the sugar-pine cone beetle* (*Conophthorus lambertianae*) *in California and Oregon, 1913–14.*

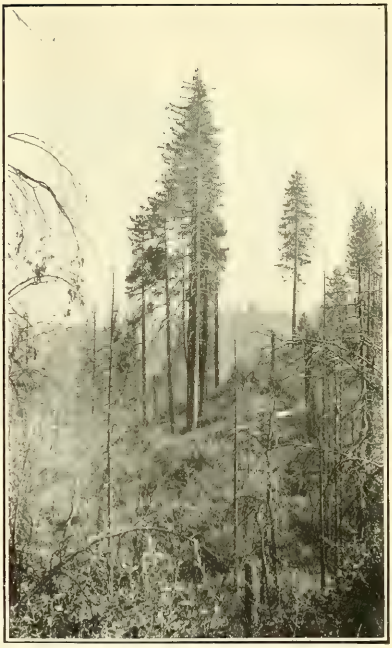
Hopk. U. S. No.	Locality.	Date of collection.	Material.	Period of spring emergence of overwintered adults.	Remarks.
11471a	Kyburz, Cal.	Apr. 11, 1913	Overwintered adults in 1911–12 cones.	May 19–May 31, 1913; 43 adults.	Breeding cage kept outdoors.
11498	Pino Grande, Cal.	May 11, 1913	do	May 14, 1913; 12 adults.	Do.
10802	do	May 26, 1913	do	Emerging May 26, 1913.	A considerable percentage of unemerged adults still in cones.
10833a–2	Hilt, Cal.	July 11, 1913	New adults in 1912–13 cones.	June 4, 1914; 6 adults.	Breeding cage kept in laboratory. Heavy emergence during Aug., 1913.
10833a–3	Ashland, Oreg.	Sept. 5, 1913	do	Apr. 19–June 4, 1914; 16 adults.	Breeding cage kept in laboratory.
10838a–2	Little Butte Creek, Oreg.	Aug. 23, 1913	do	Apr. 25–May 21, 1914.	Do.
10871a	Hilt, Cal.	Nov. 13, 1913	do	June 2–June 13, 1914.	Do.
10871a–2	do	May 2, 1914	Overwintered adults in 1912–13 cones.	May 8–May 31, 1914.	Breeding cage kept outdoors.
10884a	Ashland, Oreg.	Feb. 14, 1914	do	May 19, 1914; 1 adult.	Breeding cage kept in laboratory.
10890a	Hilt, Cal.	Mar. 13, 1914	do	Apr. 20–May 20, 1914; 10 adults.	Do.

The egg gallery is usually kept straight and close to the axis of the cone. During the early part of the season it has frequently been observed that in the small cones, from 2 to 4 inches long, the adults extend the egg gallery nearly to the outer end of the cone, depositing four or five eggs along its length, and then bore out through the scales and emerge. It has not been determined whether such emerging adults attack another cone or not, but it is reasonable to assume that this is the case. In the larger cones, from 6 to 8 inches long, which are attacked later in the season, from 15 to 30 eggs may be deposited; and as this probably represents the minimum number of eggs deposited by a pair of beetles, it is evident that very short cones do not afford sufficient length of egg gallery for the deposition of this number. Consequently a pair of parent adults may extend the egg gallery through several of the smaller cones before the egg-gallery capacity of the cone is exhausted.

As the attack continues through the latter part of June, the size of the attacked cones keeps increasing until the larger ones are from 6 to 8 inches long. The parent adults seldom emerge from these larger cones and later in the season will be found dead in the end of the egg gallery. By the 1st of July the new attack is complete. At this stage the infested cones are from 2 to 8 inches long, while the normal unattacked ones are from 10 to 18 inches long. The blighted cones are brown and stand out conspicuously on the trees. The seeds seldom form when the smaller cones are attacked, whereas the seeds of the larger cones that are attacked may reach two-thirds normal size and the outer shell may harden, but they never fill or mature.

Immediately after hatching the young larvæ begin to feed upon the scales and tissues of the now withering cone. They feed in such a manner as to leave no distinct lateral larval galleries. If the cones are opened during the larval period the small white grubs may be found in any part of the cone, the axis, scales, and often in the tender milky seeds (Pl. II, fig. 3). The development of the larvæ is very rapid. Pupæ may be found in the cones within four weeks after the first attack. By the last of June the cones which contain pupæ are dry, withered, and reddish brown in color. At about this stage the dry, withered stalks begin to break from the limbs and the blighted cones fall to the ground. All sugar-pine cones which are attacked fall from the trees before the close of the season and the broods complete their development in these fallen cones. The pupæ transform to new adults, which begin to appear by July 10, and this transformation continues throughout the summer, until by the middle of August the majority of the broods have reached the stage of new adults. Practically all of the infested cones have fallen by this time and the brood remains in these cones through





FIGS. 1 AND 2.—SUGAR-PINE SEED TREES ON BURNED AREA NEAR COLESTIN, OREG.

Photographs were made in July, 1914. The area was burned in 1910, destroying all young growth and much of the mature timber. Although the trees have put on several good crops since that date, there are scarcely any sugar-pine seedlings on the area. The seed crops have been repeatedly attacked by the sugar-pine cone beetle. (Original.)

FIG. 3.—CONES ON GROUND UNDER SEED TREES.

The large opened cones are normal. The small cones have been killed by the cone beetle. (Original.)

WORK OF CONE BEETLES IN THE CONES OF SUGAR PINE.

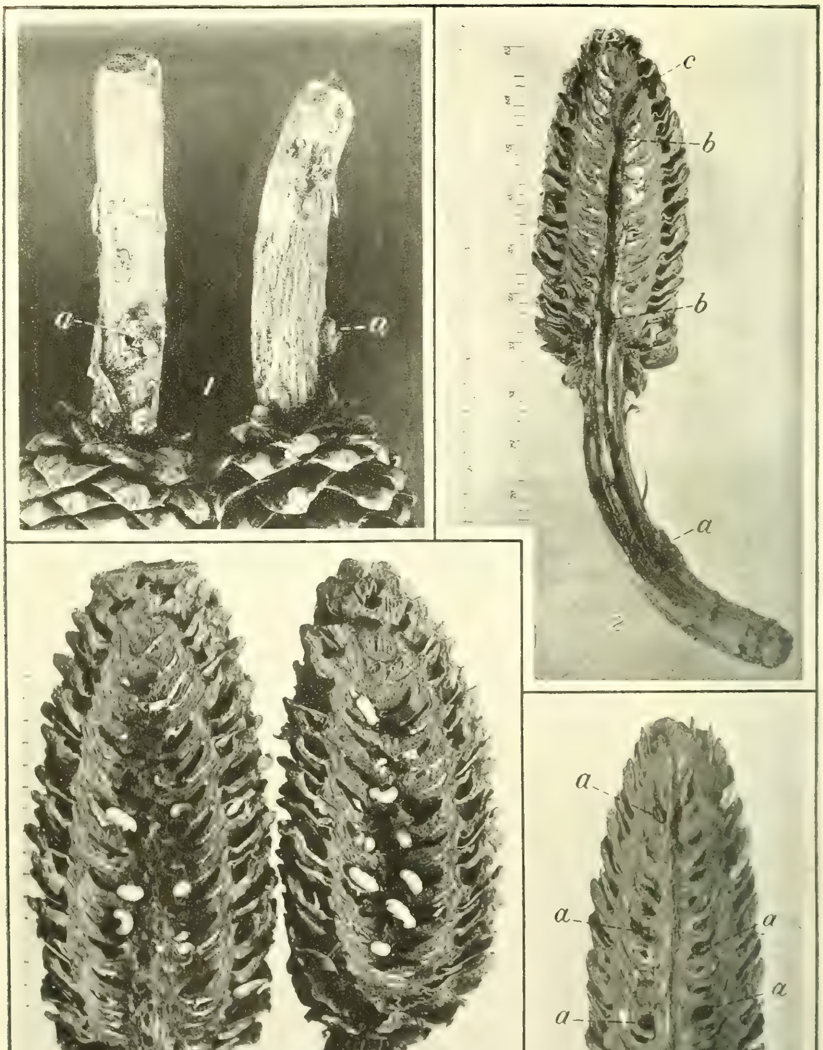


FIG. 1.—Showing stalks of beetle-killed sugar-pine cones after the cones have fallen from the tree: *a*, Entrance holes, showing small pitch tube made by beetle. FIG. 2.—A beetle-attacked sugar-pine cone opened to show tunnel and egg gallery of cone beetle: *a*, Entrace; *b*, egg gallery; *c*, extension of egg gallery to surface where adult emerges. FIG. 3.—Blighted sugar-pine cone opened to show developing broods of cone beetle. Larvæ and pupæ as found July 9, 1914. FIG. 4.—Blighted sugar-pine cone opened to show position of overwintering adults of cone beetle: *a*, Cone beetle adults. (Original.)

STAGES OF CONE BEETLES IN SUGAR-PINE CONES.

the remainder of the summer and the long overwintering period (Pl. II, fig. 4).

The new adults are not entirely dormant during this period, but feed to some extent on the dead tissue of the cone, as is apparent from the sawdust borings. The number of overwintering beetles which have been counted in a single cone varies from 1 to 36. The average, however, is from 6 to 10.

A considerable percentage of these blighted cones will always be found in which the beetles have made the attack and completed the egg gallery, but the larvæ have failed to develop. This failure of the broods is found more often in the very small and in the largest cones which have been attacked. The most successful attacks are found in the intermediate sized cones from 4 to 6 inches in length. Some of the larger cones appear to resist the beetles by drowning them out, as some trees are capable of resisting barkbeetles. In every attack, however, the cone is killed.

On certain areas great mortality to the new broods of the cone beetle, presumably through the work of an entomophagous fungus as yet not specifically determined, has been observed. In many of the cones the brood reaches the stage of full-grown larvæ, pupæ, or even new adults, and then dies. On an area near Sisson, Cal., in 1913, over 50 per cent of the cones contained these dead broods. On one area near Colestin, Oreg., in 1914, the brood developed in only 57 per cent of the attacked cones. The mortality of the developed broods amounted to 62 per cent, so the broods were finally successful in but 21.6 per cent of the cones attacked. The cause of this has not been determined and will require further study before conclusions can be drawn, although material illustrating the mortality of broods was sent in during the summer of 1914 and referred to the Bureau of Plant Industry. While it appeared to be an entomophagous fungus it has not yet been reported definitely. Few parasites of this cone beetle have been found.

All evidence points to the existence of but one generation of this species annually. The broods develop successfully only in the immature cones between 2½ and 8 inches in length. The period during which the cones may be found in this stage is so short that it allows for the development of one generation only. In August, 1913, an emergence of a considerable portion of the new generation of beetles was noted in northern California and southern Oregon. No subsequent attacks were observed on the nearly mature cones of the 1913–14 crop or upon the newly formed 1913–14 cones. No similar emergence was observed in 1912 or 1914, and the only explanation that can be given for the 1913 emergence was that it was abnormal, probably due to the unusual wet-weather conditions of that season.

The actual amount of loss to sugar-pine seed crops from this source is not easily estimated. Even though a great portion of the crop may be killed, the seriousness of the loss depends upon local factors, such as the desirability of reproduction by the natural reseeding of the infested areas or the demand for seed by local seed collectors. A number of observations have been made from 1912 to 1914 in the vicinity of Ashland, Grants Pass, and Colestin, Oreg., and in California on the Klamath, Shasta, Trinity, California, Plumas, Sierra, and Sequoia National Forests and in the Yosemite and General Grant National Parks. These observations indicate that the sugar-pine cone beetle is distributed throughout the range of the sugar pine, killing a varying percentage of the cone crops. In some places no appreciable damage is found, while in others over 90 per cent of the cones are killed by this insect. Apparently, through a period of years, local outbreaks may occur in well-defined centers of infestation anywhere throughout the range.

RELATION OF CONE-BEETLE DAMAGE TO THAT OF SQUIRRELS.

The beetle-killed cones fall during a part of the period in which the sugar-pine cones are cut by squirrels. As these rodents are the cause of the cutting and falling of a great part of the cone crop, it is only natural that some of the damage caused by the cone beetle should have been attributed to the squirrel. For this reason considerable attention was given to a study of the comparative damage during the season of 1914 from these two causes.

The first cutting of the cones by squirrels in 1914 was noted on June 25 near Butte Falls, Oreg., and later in July at Colestin, Oreg. Extensive cutting by the rodents did not begin until the middle of July, and they were active from then until the end of summer. Two species, the gray and the Douglas squirrel, were noted in connection with this damage. Important differences, however, readily distinguish this damage from that of the cone beetle.

1. Squirrels cut the stalk just above the cone and a part of the stalk is left on the limb. (Pl. V, fig. 1.) The wound where the stalk is cut may also show teeth marks of the rodent. Cones which fall from cone-beetle attack have the entire stalk attached to the cone. There are no teeth marks; a small resinous pitch tube is usually found on the stalk. (Pl. II, fig. 1.)

2. Cones cut by squirrels are usually eaten or cached by them. Beetle-killed cones are allowed to lie on the ground where they fall and are unmolested by the squirrels.

3. The majority of the sugar-pine cones cut by the squirrels are 10 inches or more in length and the seeds usually full size, although they may still be soft and milky. The majority of the beetle-killed cones are less than 8 inches; some of them not over 2½ inches. By the time the cones fall the seeds are blighted or hollow.

In order to obtain definite figures on the comparative damage from these two sources, two localities were selected in southern Oregon where the 1913–14 crop of cones was fairly good. A number of trees were selected which were so situated that the cones falling from them would not become confused with those falling from other trees. A record was made at intervals of the good cones and of those infested by the beetle or cut by squirrels. The results are shown in Table II.

TABLE II.—*Comparative loss to sugar-pine cone crop of 1914 caused by the cone beetle and squirrels.*

AREA NO. 1, NEAR COLESTIN, OREG. RECORD OF COUNT ON FIVE TREES.

Tree No.	Date.	Cones on trees.		Cones on ground.[1]	
		Good.	Beetle attacked.	Beetle killed.	Squirrel cut.
1	July 18	0	3	51	2
	July 29	0	0	54	2
	Aug. 8	0	0	54	2
	Aug. 21	0	0	54	2
2	July 18	1	5	17	1
	July 29	1	0	22	1
	Aug. 8	1	0	22	1
	Aug. 21	1	0	22	1
3	July 18	8	13	27	14
	July 29	0	2	38	22
	Aug. 8	0	2	38	22
	Aug. 21	0	0	40	22
4	July 18	16	10	31	0
	July 29	8	0	41	8
	Aug. 8	5	0	41	11
	Aug. 21	0	0	41	18
5	July 18	8	68	83	0
	July 29	6	33	115	2
	Aug. 8	4	4	147	4
	Aug. 21	1	0	151	7

AREA NO. 2, NEAR ASHLAND, OREG. RECORD OF COUNT ON THREE TREES.

1	Apr. 30	33	0	0	[2] 0
	Aug. 11	1	0	0	32
	Aug. 27	0	0	0	33
2	Apr. 30	14	0	0	[2] 0
	Aug. 11	10	0	2	1
	Aug. 27	3	0	2	8
3	Apr. 30	68	0	0	[2] 0
	Aug. 11	65	1	0	2
	Aug. 27	20	1	0	47

[1] The beetle-killed and squirrel-cut cones found under the trees on the first date were collected and put together in a pile. Those found on the following dates were collected and added to these; so that, in the above table, the number of cones on the ground at each date represents the total number found up to and including that date.

[2] Cones about one-fourth grown.

This table shows fairly well the period and rate of falling of the beetle-infested cones. It also shows the great variation in the damage.

On area 1 about 85 per cent of the cones were destroyed by the beetles, while on area 2 the attack of the cone beetle was so slight as to be almost negligible.

The damage by the cone beetle was therefore practically accomplished before that by squirrels was started. On area 1 this re-

duced the food supply of the squirrels, so that by the middle of July, when the serious cutting by the squirrels began, there was very little of the crop left for them.

Many large sugar pines standing on prominent ridges where they could easily seed several acres of the slopes below have failed to accomplish this result. One area which the author has studied closely is situated just above Colestin, Oreg., where a heavy fire in 1910 killed most of the timber on several sections, although a number of large seed-producing sugar-pine trees distributed over the area were but little injured. (Pl. I, figs. 1, 2.) However, in 1914 scarcely any sugar-pine seedlings could be found near these trees. Evidence that this area has been heavily infested by the cone beetle since the fire is plentiful, and in 1914 it destroyed 75 per cent of the crop, the squirrels completing the damage as shown in Table II under area 1.

Either the cone beetle or squirrels, but more probably a combination of the two, is responsible for the absence of satisfactory reproduction in situations where it is much needed.

THE WESTERN YELLOW-PINE CONE BEETLE.

(*Conophthorus ponderosae* Hopk.)

The general life cycle of the cone-beetle broods in yellow pine does not differ in any important respect from that in sugar pine. The first attack on second-year cones has been noted to occur from two to three weeks earlier. The period of maximum emergence occurred from May 1 to 15 on two small lots observed. Close observations on the period of attack and development in this host were made near Ashland at elevations from 1,800 to 2,200 feet. This is from 1,500 to 2,000 feet lower than the elevations at which similar observations were made on the beetles in the sugar pine. The comparative difference in seasonal history as shown by these observations will be found in Table I.

The first attack of adults in 1914 was noted on May 5, but the adults were only just starting to bore into the cone and no egg gallery had been commenced. From May 10 to June 1 continued fresh attack was noted, and the latest fresh attack occurred on June 10. By June 3 the earliest attacked cones contained a few pupæ and were beginning to turn brown and wither, so that they could easily be distinguished from the normal green, unattacked cones. By June 15 pupæ and a few new adults were found in the cones first attacked and very little fresh attack was noted. The gradual transformation of the brood progressed through the latter part of June and the first part of July, and by July 15 new adults were infesting practically all cones.

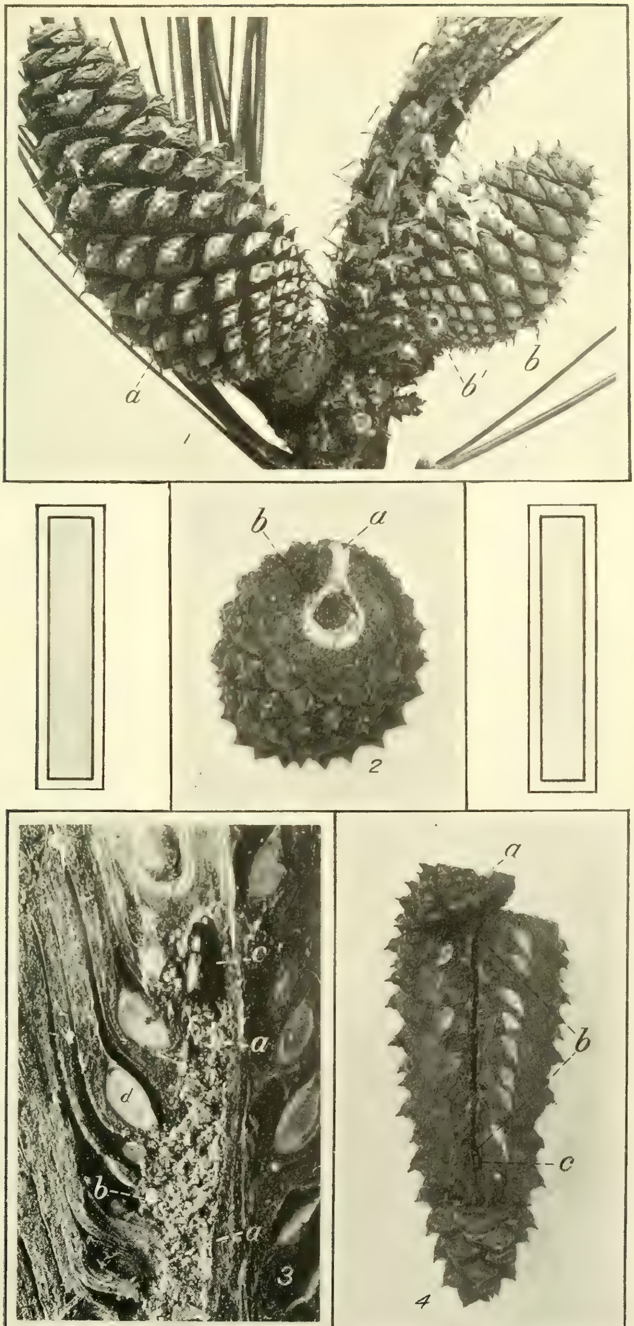


FIG. 1.—Yellow pine, showing condition of normal and blighted cone about 10 days after attack by the cone beetle: *a*, Normal cone; *b*, blighted cone; *b′*, entrance hole made by cone beetle. FIG. 2.—Blighted yellow-pine cone with part of base removed to show form of girdle made by the initial entrance of the cone beetle: *a*, Entrance; *b*, point at which the adult turned to extend the egg gallery into the axis of the cone. FIG. 3.—A portion of yellow-pine cone (near axis) opened to show egg gallery of the cone beetle, enlarged: *a*, Egg gallery, showing packed sawdust of beetle; *b*, egg; *c*, parent adult at terminus of egg gallery; *d*, immature seeds. FIG. 4.—Blighted yellow-pine cone with portion of base and scales removed to show the girdle made by the tunnel of the cone beetle and general form of the egg gallery: *a*, Entrance; *b*, egg gallery; *c*, parent adult. (Original.)

WORK OF CONE BEETLES IN CONES OF YELLOW PINE.

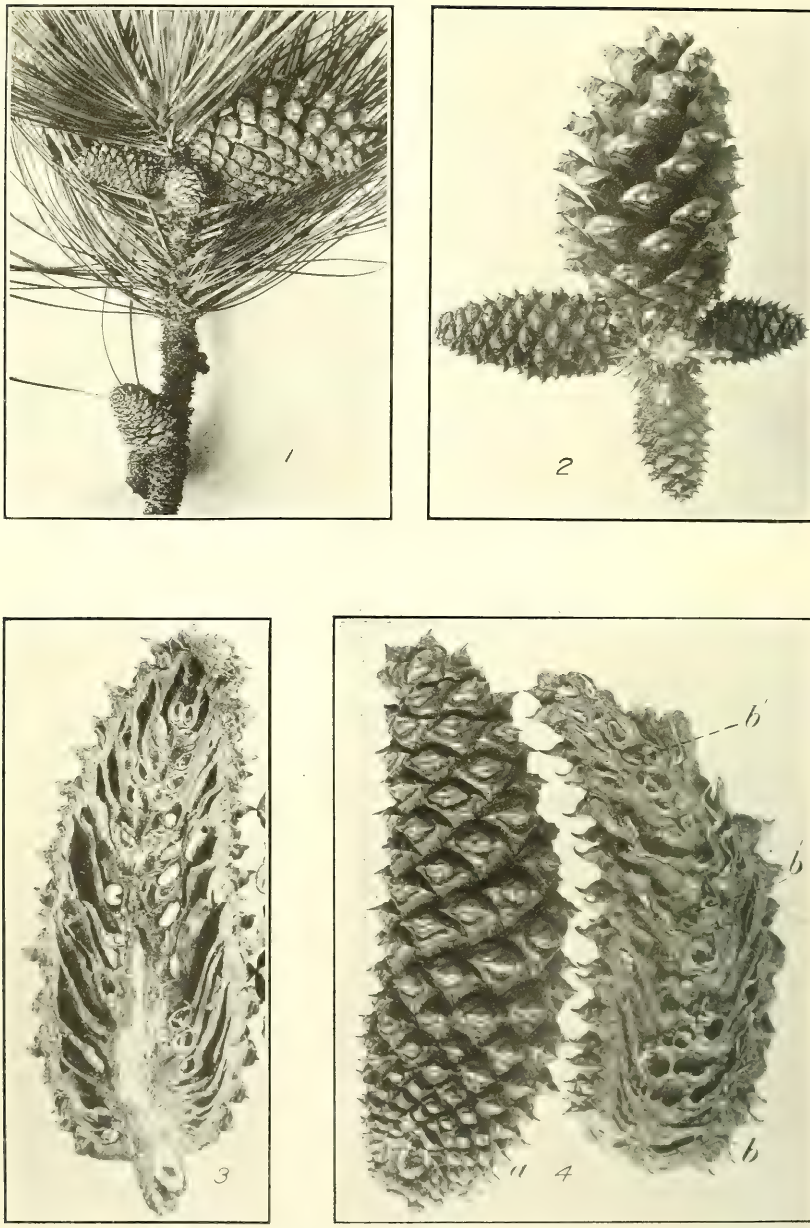


FIG. 1.—Blighted yellow-pine cones adhering to limb. This shows the position in which the majority of the yellow-pine cones are found. Near the terminal are shown three 1913-14 cones, two of them killed by the cone beetle. Farther back on the limb are the cones killed in 1912. FIG. 2.—A whorl of four yellow-pine cones, three of them killed by the cone beetle. The upper cone is normal. This shows the comparative size of the blighted and normal cones. FIG. 3.—A yellow-pine cone opened to show condition of developing brood of the cone beetle. This brood, on June 20, 1914, consisted of both larvæ and pupæ. (Slightly enlarged.) FIG. 4.—*a*, Blighted cone as it appears in overwintering condition; *b*, blighted cone opened to show damaged seeds and position of overwintering adults; *b′*, overwintering adults. (Original.)

WORK OF CONE BEETLES IN CONES OF YELLOW PINE.

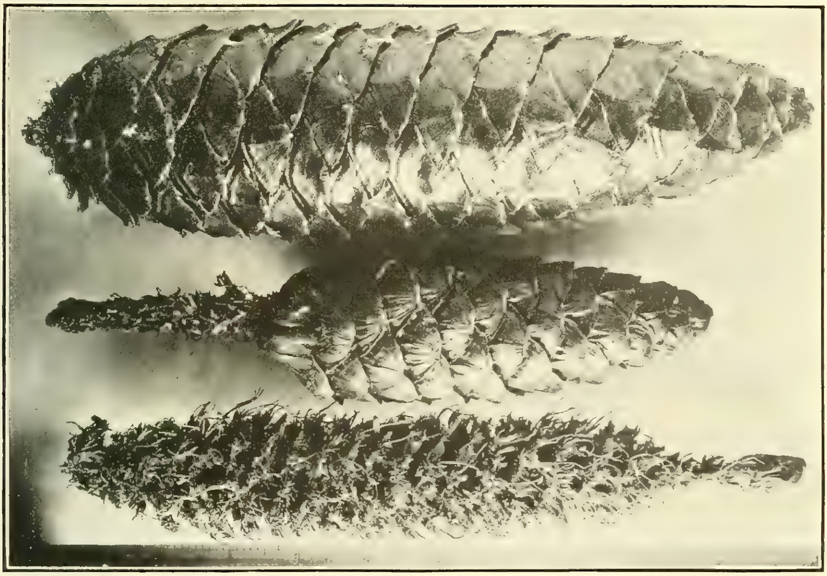


FIG. 1.—SUGAR-PINE CONES CUT BY SQUIRRELS.

The lower cone has been shucked and the seeds eaten. The cone in the center has been partly eaten. Note that the cones are cut at the base and do not have the stalk. Compare this with the blighted cones shown in Plate II, figure 1. (Original.)

FIG. 2.—YELLOW-PINE CONES CUT AND EATEN BY SQUIRRELS. (ORIGINAL.)

SQUIRREL DAMAGE TO PINE CONES FOR COMPARISON WITH THAT BY BEETLES.

Yellow-pine cones are sessile; that is, instead of being attached, each to its individual stalk, they are set closely to the limbs. At the beginning of the second-year growth they are from 1 to 1½ inches long. Necessarily the initial point of attack must differ from that on sugar-pine cones. The adult enters the cone by penetrating the scales very close to the base of the cone. Sawdust borings may be seen on the surface of the scales and quite often a tiny pitch tube collects around the entrance of the burrow (Pl. III, fig. 1*b*′). The adult does not turn directly outward through the central axis of the cone, but bores completely around the axis, forming a short spiral tunnel (Pl. III, fig. 2). This spiral twist of the tunnel before the beginning of the egg gallery is not noticeable in sugar pine, but it is characteristic of attack in yellow pine. Its result is completely to

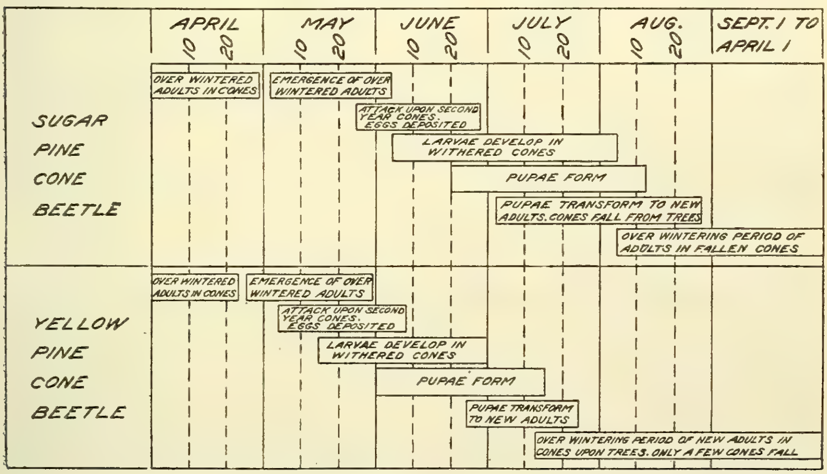


FIG. 1.—Comparative life history of the sugar-pine and yellow-pine cone beetles. Compiled from field records. (Original.)

cut off the nourishment and insure the deadening of the cone, which produces the condition necessary for the development of the larvæ. After completing this girdle at the base of the cone the adult extends the egg gallery out through the central axis (Pl. III, fig. 3). Oviposition (Pl. III, fig. 4), development of larvæ (Pl. IV, fig. 3), and transformation from pupæ to adults are in all important respects the same as with the sugar-pine cone beetle.

In a few instances attacks have been observed on the small, first-year cones just after they "put on." This seems to be a rare habit, and has only been observed where there is a great scarcity of second-year cones. Eggs are not deposited and broods can not develop in these small cones.

Beetle-killed yellow-pine cones vary from 1 to 4 inches, the length, as in sugar-pine cones, depending largely on the stage of second-year

growth when attack is made (Pl. IV, fig. 2). Yellow-pine cones, however, do not fall from the trees, and after they turn reddish brown in color they can be readily distinguished against the green foliage (Pl. IV, fig. 1). After the yellow-pine cones become dried they can not be broken readily from the limbs and quite often will be found still adhering many years after the beetles have abandoned them. The seeds may be formed, but they are invariably hollow in blighted cones (Pl. IV, fig. 4).

Occasionally a yellow-pine cone will be found that has been attacked by the beetle in which the new brood has failed to develop. The number of overwintering adults counted in the cones varied from 1 to 20, the average being from 5 to 8. The cone, however, is always killed and the damage is just as great.

The broods overwinter in the cones on the trees and emerge the following spring. (Pl. IV, fig. 4.) Adults do not appear to remain entirely dormant during this period, but feed to some extent on the dry scales and seeds. Mortality of the new broods, to any extent like that in the sugar pine, has not been observed. An examination of many infested cones of the 1913–14 crop shows that over 90 per cent of the new broods are alive.

AMOUNT OF DAMAGE.

The damage by the western yellow-pine cone beetle to yellow pine has never been noted to be as extensive as that of the species working in sugar pine. In heavy stands the loss to yellow pines is not so noticeable as it is on open isolated trees. Even in these isolated trees the amount of damage varies to a great extent on individual trees. Isolated trees at lower elevations, especially those bearing heavy cone crops, suffer most.

Two trees standing close together were selected and the cones counted as follows:

Tree No.	Green cones.	Beetle-killed cones.	Total.
1	515	448	963
2	700	65	765

The count was made August 5, 1914, at Ashland, Oreg. It shows how damage may vary with individual trees.

Estimates of the damage by this beetle necessarily depend upon the same factors as those pertaining to sugar pine. The damage, however, can not be confused with that of squirrels, as the beetle-killed yellow-pine cones adhere to the trees, while the squirrels invariably cut and either eat or cache the cones. (Pl. V, fig. 2.)

CONDITIONS REQUIRING CONTROL.

Since these insects are not a menace to growing timber, their control by direct expense is desirable only where it is found to be seriously interfering with the natural or artificial reproduction of the host tree. Under the conditions of the mature, well-stocked stands prevalent in the virgin forests of the West it is very doubtful whether the beetles ever interfere with the required natural reproduction to an extent sufficient to require artificial methods of control. Seldom is the entire crop killed and eventually through a period of years sufficient good seed is produced to replace the normal loss of trees from lightning, light fires, normal insect infestation, and overmaturity. However, conditions are entirely changed when the virgin forest has been destroyed by timber cutting, fire, or epidemic insect infestations. Yellow pine and sugar pine are rated as two of the most desirable timber species, and if the restocking of areas denuded of these species is to be accomplished by natural reproduction, full seed crops must be produced by the seed trees left on or near the areas. If the cone crops of such yellow and sugar-pine seed trees are repeatedly destroyed by the cone beetles, or if these infest them to such an extent that the destruction is completed by rodents, then the required seeding may be delayed until the ground is usurped by less valuable tree species. Under such conditions measures which will reduce the infestation of the beetle by direct expense may in the end effect a saving in the conservation of the forest. If burns or cut-over areas are restocked by artificial seeding the collection of sound, mature seed is necessary. Again, we may find that the cone beetles have so reduced the supply of cones on selected seed-collecting sites that seed can not be profitably collected. In the last case damage may be avoided by intelligent selection of noninfested seed-collecting areas. Or if the site is selected a year in advance, the infestation may be reduced and most of the seed crop saved by application of the remedy.

REMEDY.

From the discussion relating to the seasonal history of the insect it is obvious that from the last of August until the following May all the infestation within an area will consist of the broods of new adults which are overwintering within the blighted cones. It is evident that if fallen infested cones from the trees which seed in a burned or cut-over area can be raked up and burned between September 1 and May 1 a very appreciable reduction of the infestation and damage may result. In the case of sugar pine all infested cones

will be found on the ground under the trees during this period and, when the conditions seem to warrant it, burning may be done without great expense. September, October, and November would be the more favorable months for the work, as winter snow and unfavorable conditions for burning will probably be found during the winter and spring.

Seed collectors in locating areas for collecting may estimate the amount of cone-beetle damage on the trees by July 15—in some situations a month sooner—as the blighted cones by that time begin to stand out conspicuously on the trees. From these estimates the collector may determine whether or not the seed crop of the current year is too badly damaged to be profitably collected.

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Contribution from the Forest Service, Henry S. Graves, Forester,
July 21, 1915.

(PROFESSIONAL PAPER.)

LIFE HISTORY OF SHORTLEAF PINE.

By WILBUR R. MATTOON, *Forest Examiner*.

CONTENTS.

NAME AND IDENTIFICATION.

It is important to distinguish clearly the true shortleaf pine[1] (*Pinus echinata* Mill.)—variously known throughout portions of its range as "yellow," "old field," "rosemary," "two-leaf," "heart," and "spruce" pine—from other so-called shortleaf pines of the Southern States. Confusion occurs because of the custom, more or less generally prevailing throughout the South, of distinguishing only two kinds of pine, shortleaf and longleaf. Under this custom, the pine most commonly included with shortleaf is loblolly pine,[2] slash pine being classed in similar manner as longleaf pine. Shortleaf is most readily distinguished from loblolly pine by means of differences in leaf and cone, described on page 7. Other pines associated with shortleaf are the smaller, crooked-stemmed scrub pine and the northern pitch pine which seldom forms old-field stands and grows both in wetter and colder situations.

[1] Shortleaf pine was first described botanically by Miller in 1768. In 1803, the elder Michaux defined more fully the specific characteristics of the species under the name of *Pinus mitis*, widely circulated in his work on American forest trees and largely used in botanical literature. The name *Pinus echinata*, first given to the tree by Miller, was not taken up by any author of note until the publication of Sargent's Silva, Vol. XI, in 1897, and by the accepted rule of priority, this is the correct name of the species.

[2] *Pinus taeda*, know locally by various names, as "old field," "shortleaf," "swamp," "bull pine," etc.

NOTE.—This bulletin gives in detail the life history of shortleaf pine, known under various names throughout the South, where only it is found in commercial quantities.

GEOGRAPHICAL AND ECONOMIC RANGE.

Shortleaf pine occurs in 24 of the States. Its geographical range includes all the States east of the Mississippi River, except Wisconsin, Michigan, and New England, and six States west of the Mississippi. It extends from the Hudson River Valley in New York[1] south through all the Atlantic and Gulf States to eastern Texas and from West Virginia and Ohio southwestward through the Ohio and Mississippi Valleys to Missouri, Kansas,[2] and Oklahoma. The tree is distributed over more than 440,000 square miles. This is much larger than the range in the United States of white pine, its nearest competitor among the pines.

TABLE 1.—*Comparative distribution of eight species of pines having the largest ranges within the United States.*[1]

Species.	Area of distribution.	States represented.
	Sq. miles.	
Shortleaf pine	440,000	24
White pine	381,000	23
Pitch pine	360,000	19
Western yellow pine	350,000	14
Scrub pine	317,000	14
Red pine	300,000	14
Loblolly pine	295,000	13
Longleaf pine	171,000	10

[1] Areas derived from Forest Service data on the geographic distribution of pines in the United States, including approximately the exterior boundary of the botanical range.

From sea level shortleaf pine ranges up to an altitude of about 3,000 feet in the southern Appalachians. At or near sea level it covers more than 11 degrees of latitude, or about 800 miles. In the North the species is confined nearly to sea level. It attains its best development at altitudes of 600 to 1,500 feet over the Piedmont and at 400 to 1,000 feet in Arkansas. In both these localities loblolly pine reaches only to altitudes of about 500 to 600 feet, above which shortleaf is the only important southern pine up to 3,000 feet and the only conifer except scattering juniper above about 700 feet in Arkansas, Missouri, and Oklahoma.

The commercial range of shortleaf pine comprises most of the botanical range except that portion lying in the States north of Virginia and in the Ohio River basin. It includes preeminently the broad Piedmont region lying between the Appalachians and the Atlantic coastal plain from Virginia to South Carolina; the northern half of Georgia, Alabama, Mississippi, and Louisiana; all of Arkansas; eastern Oklahoma; and eastern Texas. Shortleaf pine is the only commercial conifer on more than 100,000 square miles of upland

[1] Sargent. Herbarium notes, May, 1913.

[2] Britton and Brown. Flora of Northern United States and Canada. Illustrated.

region between Virginia and northern Alabama and Mississippi. The total area of its commercial range covers not less than 280,000 square miles. The production reaches its maximum over the gently rolling and hilly country of the Mississippi basin in northern Louisiana, most of eastern Arkansas, eastern Oklahoma, and eastern Texas. In common with practically all other commercial pines, the economic range of shortleaf has become greatly reduced, and over the extreme northern part it has been almost driven out by close utilization and

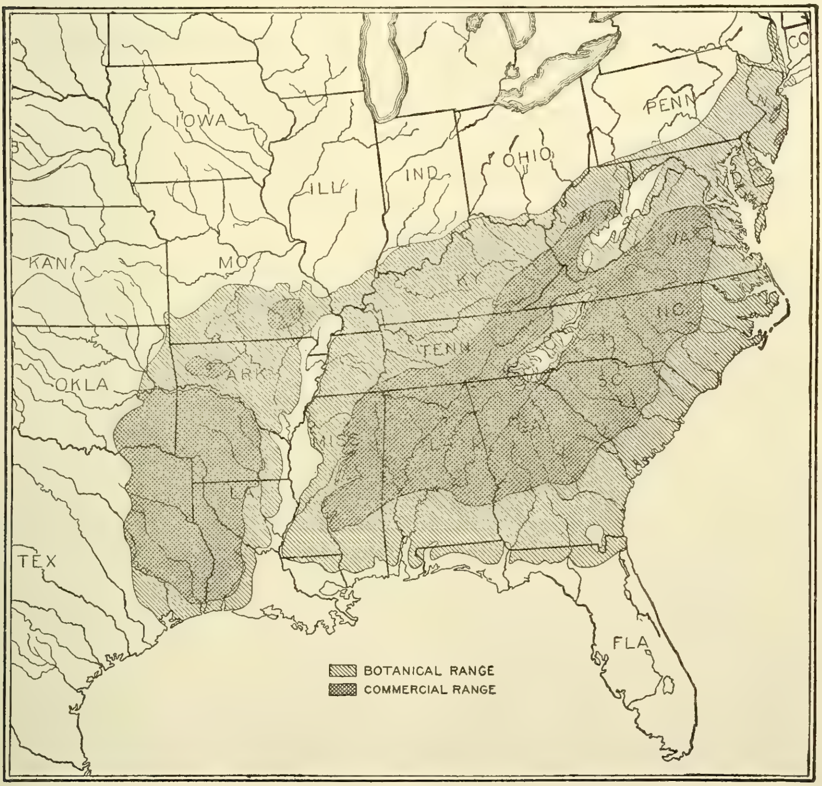

FIG. 1.—Botanical and commercial range of shortleaf pine.

the consequent encroachment of hardwoods. In the upper portions of the Atlantic coastal plain it is to a considerable extent being replaced by loblolly pine on abandoned fields. The early clearing for agriculture of the lighter and better-drained soils greatly decreased the shortleaf seed trees and correspondingly increased the relative proportion of loblolly seed trees, which were left growing along the watercourses and on low heavy soils, where they find a congenial home.

CHARACTER OF STANDS.

PURE STANDS.

Shortleaf is very well adapted for growth in pure stands, and it occurs extensively in this form of forest. The stands are not usually continuous over large areas, but are separated by mixed stands of pines and hardwoods. Stands of pure shortleaf pine once covered a much larger area than at present. It is doubtful whether shortleaf is now found in pure type on more than from 20 to 40 per cent of its former range.

Mature shortleaf occurs over a large region centering in western Arkansas and northern Louisiana. This is the last extensive region of virgin shortleaf forest left in the gradual progress of the lumber industry southward and westward following the coast line. At elevations of 400 to 1,200 feet the hilly country supports heavy stands of timber, which, however, are being lumbered at a rapid rate. In the higher mountainous regions, including the southern Appalachians from 1,000 to 2,000 feet in elevation and the Arkansas and Ozark National Forests, the warm south-facing slopes are generally covered with pine in pure stands, and the northerly slopes with little else than hardwoods, chiefly oaks and hickories.

A considerable proportion of the pure stands of shortleaf is found in old fields formerly under cultivation. Here the factor of early competition with hardwoods was eliminated and the pine took complete possession. This form of second-growth forest occurs extensively from Virginia southward and westward throughout its entire commercial range and aggregates probably more than 68,000 square miles.[1] It represents practically all the land within the shortleaf-pine belt that has at any time been cleared and subsequently abandoned. During a period of 10 to 20 years, commencing in 1861, a vast acreage of such lands was "turned out" all through the South; but the process of "clearing up," "working out," and "turning back" land has been in common practice for a century or more in the older parts of the Southern States.

MIXED STANDS.

CONIFERS.

In its geographical relation to the other eastern pines of commercial importance, shortleaf occupies a position characteristically intermediate between white and Norway pines on the north and loblolly and longleaf on the south. Between these two widely separated groups of important commercial pines, shortleaf occupies and dominates a broad strip of country.

[1] Based upon general forest studies in practically all of the States, and detailed examination of 21 counties in North Carolina.

Altogether 10 different species share in varying degree the range of shortleaf. Pond and slash pines and spruce pine merely overlap along the southern margin, but pitch and scrub pines share as much as one-third to one-half the botanical range. In parts of Virginia and North Carolina, scrub pine occurs in varying proportion in the mixed shortleaf conifer stands,[1] particularly in old fields, and it succeeds in getting a strong foothold in the poorer soils, dry pastures, and waste places. On the lower or warmer side, shortleaf throughout practically its entire range associates extensively with loblolly pine. In this association the two maintain, to a large degree, the relation of complementary species, loblolly holding the heavier, moist soils and shortleaf the drier and lighter soils. Valuable and extensive commercial forests of this character occur in Georgia, Alabama, Mississippi, Texas, and especially heavy stands in Arkansas and Louisiana. Both of these pines to some extent, and particularly loblolly, are replacing the slower-growing longleaf on all situations, except the driest and most sandy soils, throughout their region of contact.[2] In the longleaf region shortleaf occurs generally in groups or small stands on favorable situations, but in large areas west of the Mississippi the two occupy practically the same soil type, and in mixture they make up heavy stands of maximum development.

HARDWOODS.

A large number of broadleaf species are associated with shortleaf through its extended range. Oaks and hickories, however, are so constant in their association as to be characteristic in many of the mixed stands. Over the Northern Atlantic States chestnut oak, yellow oak, and red oak are the most typical associates. From Virginia southward throughout the Piedmont country, lying between the coastal plain and the lower slopes of the mountains up to 2,500 feet, shortleaf still maintains its position generally as the dominant tree in mixture with the upland oaks and hickories. The primary associated species are yellow and Spanish oaks, big-bud and bitternut hickories, and, on the thin ridges, post oak and black-jack oak. The amount of shortleaf in the mixture varies widely, but throughout the eastern range represents usually from 35 to 60 per cent of the stand. In the hilly and mountainous parts of Arkansas, the mixed shortleaf and loblolly type gives way at elevations above about 400 feet to heavy stands of nearly pure shortleaf up to about 1,000 feet, whence

[1] Following are botanical and common names of pines mentioned:

Loblolly pine (*Pinus taeda* Linn.).
Longleaf pine (*Pinus palustris* Mill.).
Pitch pine (*Pinus rigida* Mill.).
Pond pine (*Pinus serotina* Michx.).
Table Mountain pine (*Pinus pungens* Michx.).
Norway pine (*Pinus resinosa* Ait.).
Scrub pine (*Pinus virginiana* Mill.).
Slash pine (*Pinus caribaea* Morel.).
White pine (*Pinus strobus* Linn.).

[2] Ashe, W. W. Proceedings of the Society of American Foresters. Vol. V, No. 1, p. 84.

the shortleaf-hardwood mixed forest ascends the mountain slopes to about 2,000 feet. The prevailing associates west of the Mississippi River are oaks and hickories, particularly yellow oak, bitternut and pignut hickories; on the dry ridges post and black-jack oaks; and in the fresher soils white and red oaks, big-bud or mocker-nut hickory, and red gum.[1] The commercial importance of all the hardwoods typically associated with shortleaf is comparatively small, except white oak in the region of its better development. Several inferior species, including persimmon, sassafras, and dogwood, are nearly everywhere represented in the mixture.

TABLE 2.—*Forest composition of the Arkansas and Ozark National Forests.*[1]

Species.	Arkansas National Forest.[2]				Ozark National Forest.[3]	
	Total stand.	Per centage of total stand.	Diameter.		Total stand.	Per centage of total stand.
			Average.	Maximum.		
	Board feet.		*Inches.*	*Inches.*	*Board feet.*	
Shortleaf pine	1,500,000,000	75.00	18	34	108,890,000	10.15
White oak	300,000,000	15.00	17	36	605,925,000	56.51
Red and black oak	100,000,000	5.00	16	18	252,809,000	23.57
Hickory	350,000	.02	16	18	40,271,000	3.76
Red gum	3,348,000	1.67	16	22	63,248,000	5.90
Miscellaneous	96,302,000	3.31			1,174,000	.11
Total	2,000,000,000	100.00			1,032,317,000	100.00

[1] Figures for the Arkansas Forest secured during reconnaissance in 1913. Figures for Ozark Forest from Bulletin 106, Forest Service, "Wood-Using Industries and National Forests of Arkansas."
[2] Area of Forest, 750,000 acres.
[3] Area of Forest, 481,575 acres.

The percentage of shortleaf is relatively small in the Ozark, which is farther north, and increases outside of both Forests because of the lower elevations and warmer situations.

Under virgin conditions the progressive changes within this mixed type resemble in some respects those that occur with white pine. By the thinning or removal of the valuable shortleaf pine, opportunity has been afforded for the more rapid reproduction of tolerant hardwoods already on the ground. Thus, some territory formerly dominated by shortleaf in mixture is now held almost exclusively by hardwoods.

[1] Names of hardwoods mentioned:

Big-bud hickory (*Hicoria alba* Britt.).
Black gum (*Nyssa sylvatica* Marsh.).
Black-jack oak (*Quercus marilandica* Muenchh.).
Dogwood (*Cornus florida* Linn.).
Chestnut oak (*Quercus prinus* Linn.).
Persimmon (*Diospyros virginiana* Linn.).
Pignut hickory (*Hicoria glabra* Britt.).
Post oak (*Quercus minor* (Marsh.) Sarg.).
Red gum (*Liquidambar styraciflua* Linn.).
Red maple (*Acer rubrum* Linn.).
Red oak (*Quercus rubra* Linn.).
Sassafras (*Sassafras sassafras* (Linn.) Karst.).
Scarlet oak (*Quercus coccinea* Muenchh.).
Spanish oak (*Quercus digitata* (Marsh.) Sudw.).
White oak (*Quercus alba* Linn.).
Yellow oak (*Quercus velutina* Lam.).

SIZE, AGE, AND HABIT.

Over much of its range the average height attained by shortleaf is between 80 and 100 feet, and in regions of better development between 100 and 120 feet, with a maximum of about 130 feet. Mature diameters of from 2 to 3 feet are most common; those of 4 feet are rare except in trees grown in the open. The tree commonly reaches an age of between 200 and 300 years, a maximum of about 400 years being occasionally attained.

In size, shortleaf holds about middle ground between longleaf and loblolly pines. Loblolly grows to an equal height and a greater diameter, but is not so straight a tree. Longleaf averages a little higher, but has a somewhat smaller trunk at maturity.

FORM.

A long clear straight bole with small taper and short crown makes shortleaf pine almost an ideal tree for the saw. These characteristics are so much more pronounced in shortleaf than in several of its pine associates, for example, pitch, scrub, and loblolly pine, that they serve commonly as distinguishing marks. In early life the tree has a narrow pyramidal stem, which later becomes more cylindrical (Pls. I and II). Tables showing the form or taper of the stem, both outside and inside the bark, will be found in a forthcoming bulletin on the importance and management of shortleaf pine. These include tables for North Carolina and Arkansas, showing inside bark measurements at intervals of 8.15 feet above a 1.5 foot stump for trees from 40 to 120 feet in height and of corresponding diameter classes. The tables are adapted for use in calculations of cubic volume of saw timber from 8 and 16 foot logs, allowing 0.3 foot additional length for each 16-foot log. The butt taper at 1-foot intervals of trees of various diameters is also shown, and there is a table of tapers outside the bark at 10-foot intervals above the ground for trees from 40 to 90 feet in height.

CROWN AND BARK.

A short crown composed of numerous small branches, forming a narrow pyramidal head, permits of the close density which characterizes shortleaf-pine stands. This inherent narrow crown habit is well shown in trees grown in the open, where it is conspicuous even to an advanced age. Although changes take place in the relative demand of the crown for light after the period of maximum height growth (about 50 to 70 years), the change in the general shape of the crown is slight. While the crown of longleaf in early life has about the same outline as shortleaf, though less dense, in later life it broadens out far more. Loblolly maintains a much wider and heavier crown at all periods of life than either of the other important southern pines. This habit is more pronounced on the drier soils; hence in

the upper portions of its range, where associated with shortleaf, this difference in outline and internal branching of the crowns becomes striking and serves as a distinguishing characteristic.

In keeping with the small, close crown are the short, slender leaves of shortleaf pine. The leaf characteristics, together with the cone, afford the best means of identifying the species. (Fig. 2.) Special notice of this is essential, because confusion prevails generally in distinguishing the various pines. Shortleaf belongs distinctly to the two-leaf group of pines. On the more vigorous portions of the crown, however, three leaves in the bundle are not uncommon. The leaves are mostly 3 to 5 inches long, in some localities appearing en masse of a slightly bronzed or pale-green color, in contrast to the glaucous or blue-green color in other localities or regions. Short shoots and colonies of sessile leaf bundles are often scattered along the trunk and over the upper sides of the larger branches. These are found on the pitch pine of the North and the pond pine of the South; but since they occur in none of the important southern timber pines except shortleaf, they serve practically as a characteristic distinguishing shortleaf from both loblolly and longleaf pines. The size of the cones ("burrs") aids in recognizing shortleaf when otherwise it might be confounded with loblolly pine, its most common associate in the lower soils. The small cones of shortleaf (from 1½ to 2½ inches in length) when open on the tree appear to be about the size of pigeon eggs; those of loblolly (from 3 to 5 inches in length) about the size of duck eggs. The individual scales composing the cone in shortleaf are armed with slender, needle-pointed prickles, broken off more easily than the stouter persistent prickles of loblolly cones. The seed of shortleaf (described on p. 19) is likewise much smaller than that of loblolly pine.

A difference in the bark of shortleaf and loblolly is readily perceptible up to the beginning of old age. The bark of loblolly is on the average thicker, more deeply furrowed and ridged, and somewhat darker in color than that of shortleaf. After maturity these differences in bark become less marked, or disappear.

RELATION OF CLEAR LENGTH TO CROWN.

Measurements taken in shortleaf stands of average density show much regularity in the relation of the length of the living crown to the total height of the tree. In stands about 10 feet in height the depth of the canopy averages 5 feet, or one-half the height of the stand. Above this height the canopy gradually becomes proportionately shorter, until at 80 feet clear lengths of 45 to 55 feet are reached. This is from about 60 to 70 per cent of the total height, varying with different qualities of site. The crown is relatively longer, in proportion to the total height of the tree, on the poorer situations, and, conversely, the clear length of the stem is shorter.

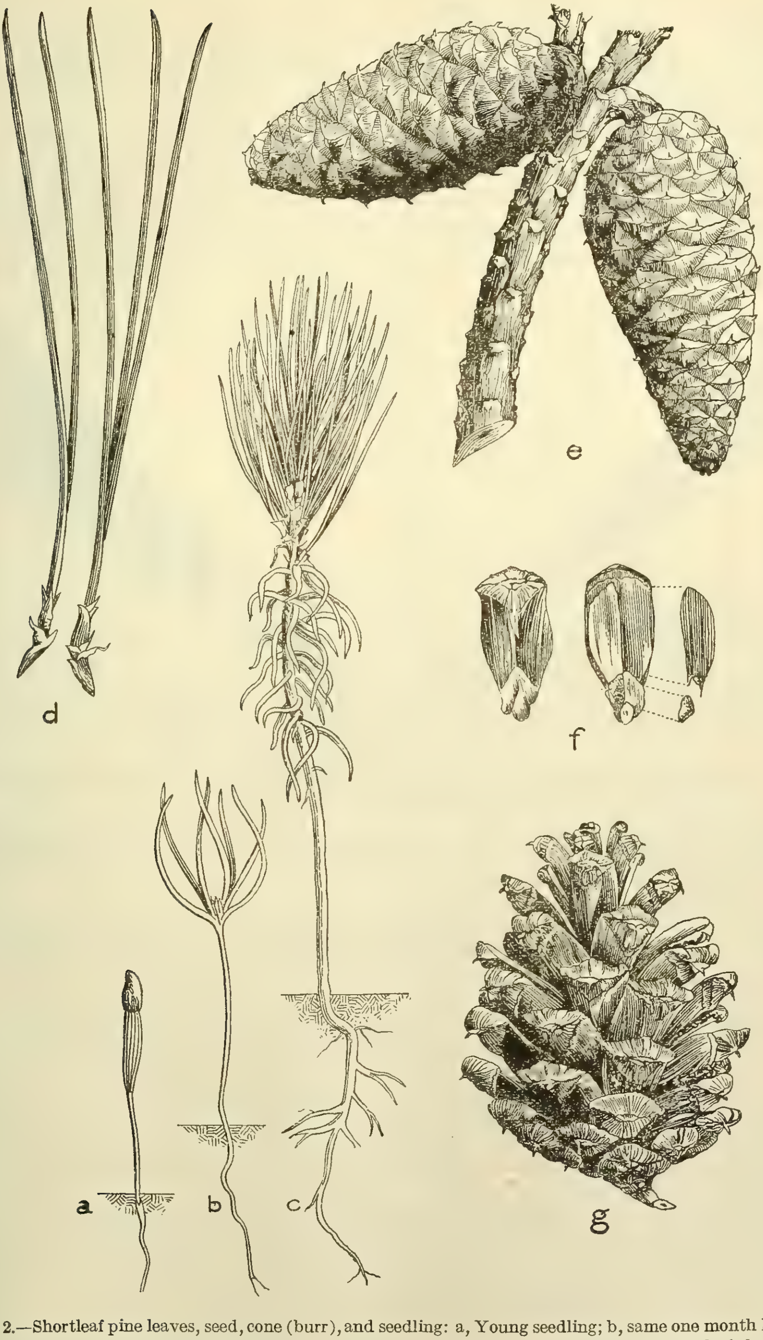

Fig. 2.—Shortleaf pine leaves, seed, cone (burr), and seedling: a, Young seedling; b, same one month later; c, seedling at end of first season showing early bundles of true leaves; d, two-leaf and three-leaf clusters; e, branch with mature closed cones (burrs); f, cone scale and seed with wing detached; g, mature cone opened. (Drawn to scale from actual specimens.)

Figure 3, based on measurements of 34 well-stocked shortleaf pine stands in Arkansas, represents graphically the proportion of clear length to crown length for trees of various heights on the better and poorer quality of situations.

The lengths of the crown and clear stem and their proportion of the total height of the tree are given in Table 3. In New Jersey 70-year-old stands 65 feet high had practically the same actual depth of canopy as vigorous stands 50 years old and 80 feet in height in Arkansas. The proportion of clear length to total height in New

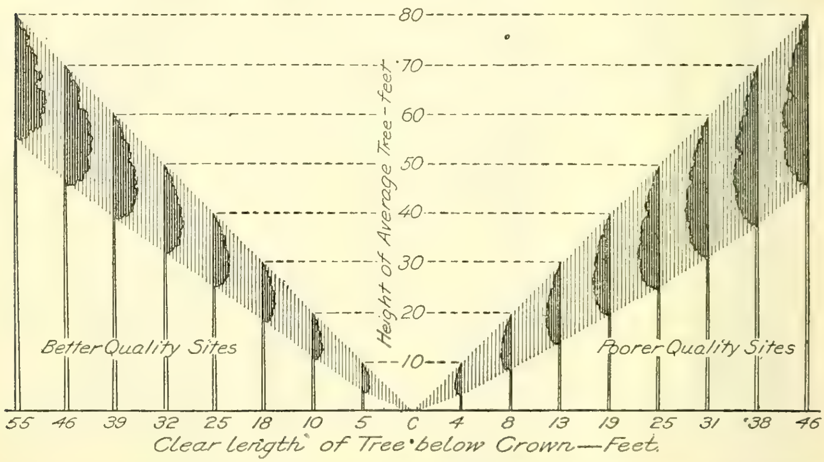

FIG. 3.—Relative proportions of clear length and crown depth for shortleaf pine of various heights on better and poorer qualities of site in Arkansas.

Jersey was about 48 per cent, as compared with 70 per cent for the better stands in Arkansas.

TABLE 3.—*Clear length and crown length of dominant trees in well-stocked stands of shortleaf pine in Arkansas.*

Total height of tree (feet).	Better quality site.				Poorer quality site.			
	Clear length.		Crown length.		Clear length.		Crown length.	
	Feet.	*Per ct.*	*Feet.*	*Per ct.*	*Feet.*	*Per ct.*	*Feet.*	*Per ct.*
10	5	50	5	50	4	40	6	60
20	10	50	10	50	8	40	12	60
30	18	60	12	40	13	43	17	57
40	25	63	15	37	19	47	21	53
50	32	64	18	36	25	50	25	50
60	39	65	21	35	31	52	29	48
70	46	67	24	33	38	54	32	46
80	55	69	25	31	46	57	34	43
90	63	70	27	30	53	60	37	40

CROWN SPREAD AND TREE DIAMETER.

In well-stocked stands of shortleaf pine a very close relationship has been found to exist between the diameter of the tree at breast height and the diameter of the crown. This relationship is striking in its

constancy and, so far as is known,[1] has never before been found to exist in any North American tree species. It was found to hold true for all crown classes within a range of ages from 20 to 80 years, representing average diameters up to about 16 inches. Indications point to this relation holding true beyond 80 years, although no measurements in pure shortleaf pine have been made. Later measurements by Prof. H. H. Chapman, of Yale Forest School, indicate a

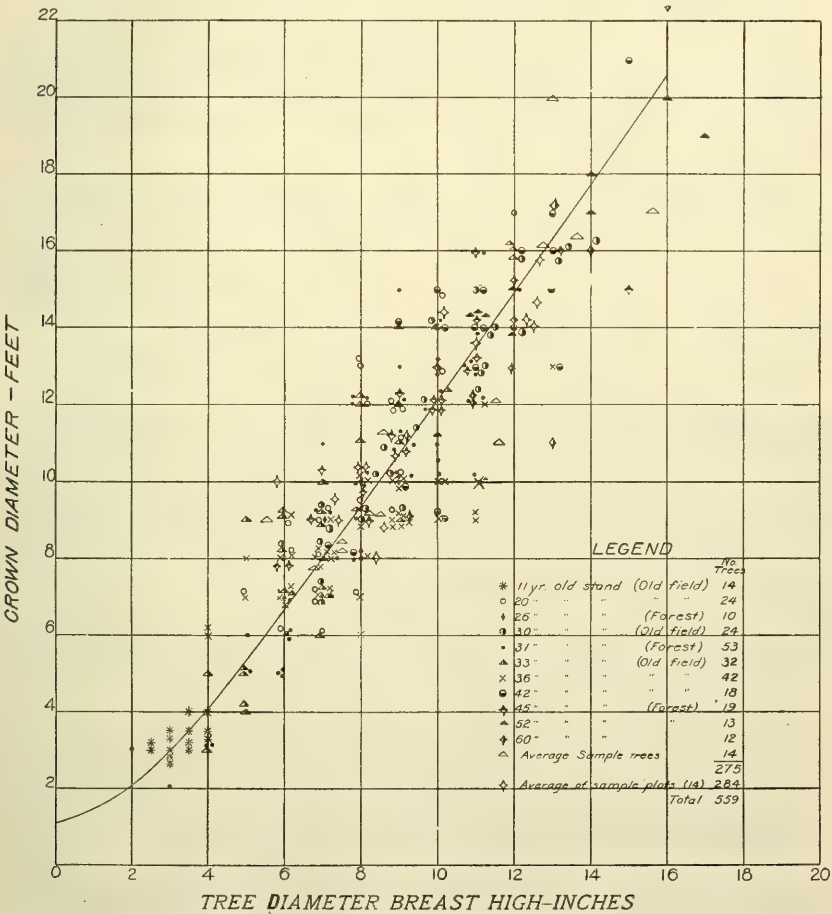

FIG. 4.—Relation of crown width to diameter of tree. (Shortleaf pine, 11 to 60 years old, in Arkansas.)

constant relation between the diameter and crown in mixed shortleaf and loblolly pine stands from 80 up to 200 years; also recent deductions from yield and growth data of red spruce show a definite relation existing between basal area and growing space in even-aged stands between 20 and 100 years.[2]

The evidence from which the conclusion is drawn is shown in figure 4, based on 545 trees on 25 sample plots, representing 16 different ages,

[1] Determined in January, 1913, from measurements taken in November and December, 1912.
[2] By L. S. Murphy, Forest Service.

and the average tree on each of 14 other sample areas, or a total of 559 trees. All the trees of the three crown classes in the stand and on the different qualities of site are represented. Under the influence of all these different factors, which are considered variables in matters of tree growth and volume increment, the size of both diameter and crown spread have been found to vary uniformly and in the same direction. This intimate relationship between tree diameter and crown spread is apparently an expression primarily of tolerance or relative demand of the species for light.

Table 4 gives the average crown spread in feet of each breast-high diameter class from 5 to 16 inches. It shows a perfect regularity between the size of the tree and the space occupied by its crown, irrespective of age and vigor.

The table shows that for each increase of 1 inch in tree diameter the crown spread increases 1.4 feet in Arkansas and 1.75 feet in New Jersey. This difference in rate is probably due to the effect of different climatic conditions upon the tolerance of the species. During earlier life up to about 15 years the relation appears to be in the ratio of 1 foot of crown spread to each inch in tree diameter.

This law of growth finds practical application in determining for any specified diameter class the total number of trees that can most profitably be grown per acre in a well-stocked stand. Since diameter is a direct function of age in any given quality of situation, the tree density on the ground at any desired age can likewise be ascertained. Knowledge of this sort is fundamental in working out problems of thinning, cutting, and final yields of timber.

TABLE 4.—*Relation of tree diameter and crown diameter for shortleaf pine trees in fully stocked stands for all ages from 20 to 80 years—Contrast of regional difference for Arkansas and New Jersey.*

Tree diameter breast high (inches).	Crown diameter.					
	Favorable region (Arkansas).			Unfavorable region (New Jersey).		
	Crown diameter.	Amount of increase.	Difference in crown diameter and tree diameter.	Crown diameter.	Amount of increase.	Difference in crown diameter and tree diameter.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
5	5.2		4.8	3.25		2.85
6	6.6	1.4	6.1	5	1.75	4.5
7	8	1.4	7.4	6.75	1.75	6.15
8	9.4	1.4	8.7	8.50	1.75	7.8
9	10.8	1.4	10.05	10.25	1.75	9.5
10	12.2	1.4	11.4	12	1.75	11.21
11	13.6	1.4	12.7	13.75	1.75	12.85
12	15	1.4	14	15.50	1.75	14.5
13	16.4	1.4	15.3			
14	17.8	1.4	16.6			
15	19.2	1.4	17.95			
16	20.6	1.4	19.3			

ROOT SYSTEM.

Having strongly developed taproot and laterals, the tree is seldom thrown by wind except in the case of tornadoes. This root system also enables the tree to thrive in relatively dry situations. Taproots 14 feet deep have been found on 8-year-old saplings, which shows the ability of the tree to search for moisture. (Pl. I.) This root habit may account, in part at least, for the wide geographical distribution of shortleaf pine, and, within much of its range, its supremacy over all other conifers, except red juniper, in successfully occupying the driest upland soils and exposed ridges. It is significant that shortleaf pine, which maintains throughout life a higher tree density in pure stands than any other eastern or southern commercial pine, possesses inherently both a narrow crown and deep root system. The distribution of loblolly pine over the tideland districts and along watercourses and the absence there of shortleaf pine is undoubtedly due to an ecological effect of root development and inherent adaptation.

DEMANDS UPON SOIL AND CLIMATE.

SOIL.

Shortleaf occurs on a wide variation of soil types, ranging from the gravels and sands to stiff clays. In respect to soil moisture, however, its requirements in one particular are more exacting; namely, under all conditions, shortleaf avoids very poorly drained or wet situations. Its home is essentially on the better-drained soils. In New Jersey it grows on the low ridges of gravelly loam, associated with chestnut oak. Over the extreme lower portion of the Atlantic coastal plain, from North Carolina through southern Georgia, Alabama, and Mississippi, its occurrence is always on the well-drained ridges and hummocks. The physiography and soil types of the Piedmont region, from the upper coastal plain well into the lower slopes of the mountains, are favorable to its vigorous growth. The deep, well-drained, gravelly or clayey loam soils of this region favor shortleaf but discourage loblolly, which is much inferior in ability to withstand drought. In the lower shortleaf range toward the southern coasts the lighter grades of sandy soils are occupied by longleaf, which possesses remarkable tolerance for deep and very dry soil conditions.

CLIMATE

The broadness of the climatic conditions favorable to shortleaf pine is clearly indicated by the tree's wide geographical range The range of temperature is from the mean annual temperature of 48° F. in northern New Jersey, through 60° in central Arkansas, to 70° in southeast Texas. Of greater significance is the difference be-

tween the midwinter (January) mean of 26° in northern New Jersey and the midsummer (July) mean of 84° in southeast Texas. Within its geographical range occurs a total temperature range of 134° F., from a minimum of −22° in New Jersey to a maximum of 112° in northern Louisiana. The length of the growing season is indicated approximately by the period during which killing frosts do not occur. In New Jersey this period averages only five months, from May 1 to October 1; in northern Louisiana it is a little less than eight months, from March 16 to November 8. There is a variation in snowfall from an average of 40 inches at the north to none whatever over the southern range of the species.

In the northeast, the 45-inch line of annual precipitation closely parallels the northern limit of shortleaf's range, and the line marking an average of 40 inches of precipitation about coincides with its southwestern boundary in Kansas, Oklahoma, and Texas. Shortleaf advances farther into this region of low relative humidity than any other pine, and in its advance into Texas falls behind only cypress and eastern red cedar. The belt of maximum development of shortleaf—northern Louisiana and Arkansas and the southern Piedmont—coincides strikingly with the rainfall zone of 45 to 55 inches, or an average of 50 inches.

In general, shortleaf pine reaches its best development under (1) a mean annual temperature of about 55° F., from a 35° average for the coldest months of the year to a 75° average for the warmest; (2) an annual precipitation of 45 to 55 inches, distributed through at least nine months of the year; and (3) in deep, porous or well-drained, clayey, or gravelly loam. In less favorable conditions, the species shows considerable vigor of growth over regions of wide variation in temperature, atmospheric moisture, soil composition, and, excepting in the heavier, poorly drained soils, soil moisture. In demands upon both moisture and heat, shortleaf is clearly the least exacting of the important southern pines, which may be put in the following order: Slash, longleaf, loblolly, shortleaf.

LIGHT REQUIREMENTS.

Shortleaf pine requires an abundance of direct overhead light fof development, yet at the same time it possesses to a remarkable degree both the power to withstand suppression for many years and the capacity of rapid recovery following suppression. The intimate relation between light supply and growth in early life is graphically shown in figure 5, drawn to scale from an 11-year-old crowded shortleaf-pine stand. The adjacent stands cut off all side light and slightly reduce the overhead supply. The height growth increases at an accelerated rate as the distance from the adjacent stand increases, reaching its normal level of 22 feet at a distance approxi-

mately the same as the height of the marginal trees. Incidentally this close response in growth to varying degrees of light makes shortleaf a good recorder of unusual climatic or other events which strikingly alter existing light relations. Typical examples of this are given on page 32, under the discussion of recovery after suppression.

Because of its inherently narrow crown and medium light requirements, the density of shortleaf stands remains high to a relatively advanced age. So many factors enter into the problem that it is impossible to determine the absolute position of shortleaf in the scale of light requirements without a much greater number of exact measurements. To compare it, however, with other southern pines, under similar conditions of soil, heat, moisture, and age, shortleaf throughout life requires less light for development than longleaf, does not in early life tolerate shade so well as loblolly, but retains longer the

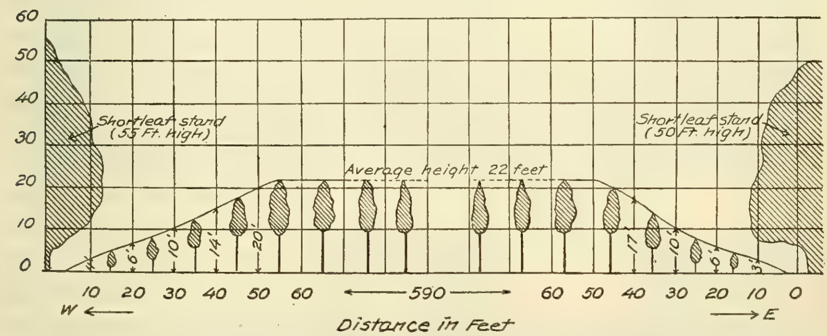

FIG. 5.—Effect of light supply upon height growth, shown by a vertical section through a 2-year-old shortleaf stand. Fully stocked, even-aged shortleaf stand, 11 years old and 22 feet high. (Drawn from actual stand.)

power of growth under limited light supply, showing this retention of power by a relatively later and slower decrease in tree density.

NATURAL THINNING AND STAND DENSITY.

The dependence of shortleaf on a full supply of light in early life is seen in the rapid reduction of very high tree density in natural unthinned stands. A square rod of 8-year-old saplings, encroaching upon a cotton field in Nevada County, Ark., contained a stand of about 58,000 per acre. At 10 years, as many as 25,000 to 40,000 trees per acre over limited areas are not uncommon. At 20 years the normal stand contains from 900 to 1,200 trees.

In fully stocked stands natural thinning progresses very rapidly during the first decade and at an increasingly slower rate during the following 20 to 30 years. After this period the loss of trees is very noticeably gradual for the remainder of life. Natural thinning is most rapid and culminates earliest in the best quality of situations both from a regional and local standpoint. In the central Mississippi

Valley region the first general period ends somewhere between the ages of 40 and 50 years, depending upon the local situation; in the central Atlantic coast belt apparently between 55 and 70 years. Figure 6, showing progressive stages of natural thinning and crown, classed according to age, represents actual numbers of trees and outlines of crowns as they existed in four fully stocked stands in Arkansas measured for growth and yield. The 20-year-old stand contained 800 trees per acre; the 33-year-old stand, 580 trees; the 42-year-old stand, 400 trees; and the 52-year-old stand, 320 trees per acre.

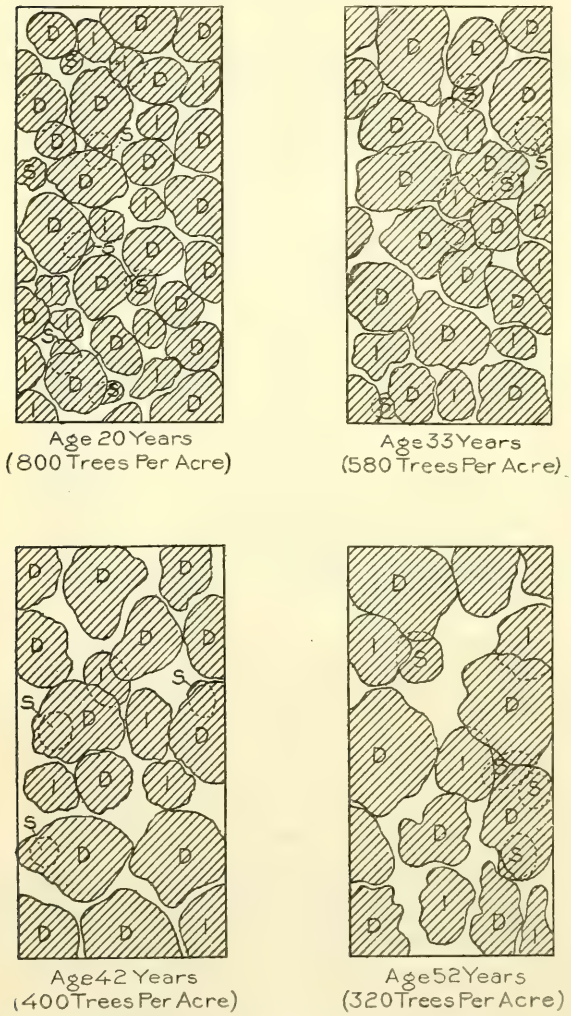

FIG. 6.—Progressive change in tree density by natural thinning in pure even-aged stands of shortleaf in Arkansas: D, Dominant classes; I, intermediate; S, suppressed classes. Areas, 33 by 66 feet. (Drawn from actual stands.)

Shortleaf pine shows progressive changes in the character of the forest canopy other than the mere reduction in number of trees. These changes are well illustrated in figure 6 for stands from 20 to 50 years old. In early life the tree crowns are approximately circular in outline and closely approach each other, leaving very little unoccupied space. At the age of 50 years, however, the tree has become less tolerant, the crowns are quite irregular in outline, and crown isolation leaves relatively large light spaces in the canopy. The slow rate of natural thinning after about 50 years undoubtedly is accompanied by relatively small changes in the tolerance of the tree. The climax of lateral growth or spread of the branches characteristic of the species seems to be closely ap-

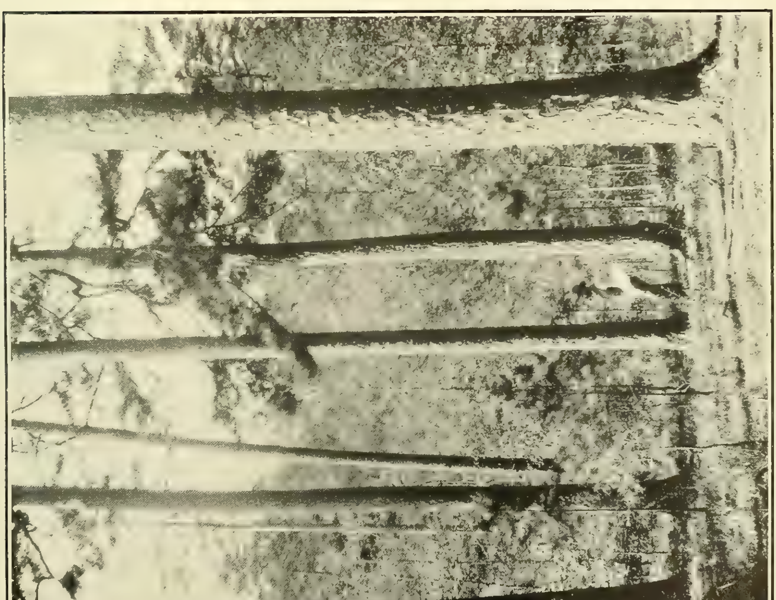

FIG. 1.—MATURE SHORTLEAF PINE, AGE ABOUT 170 YEARS.

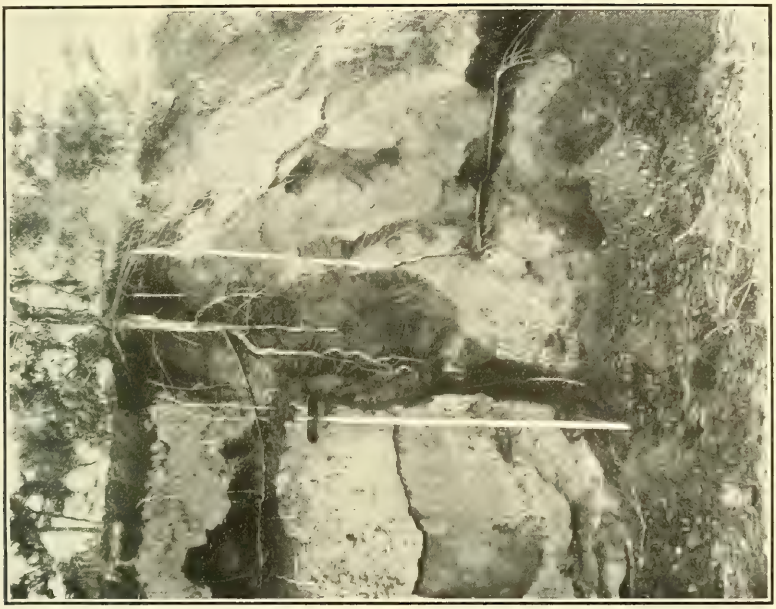

FIG. 2.—ROOT SYSTEM OF SAPLING, 7 FEET IN SUBSOIL.

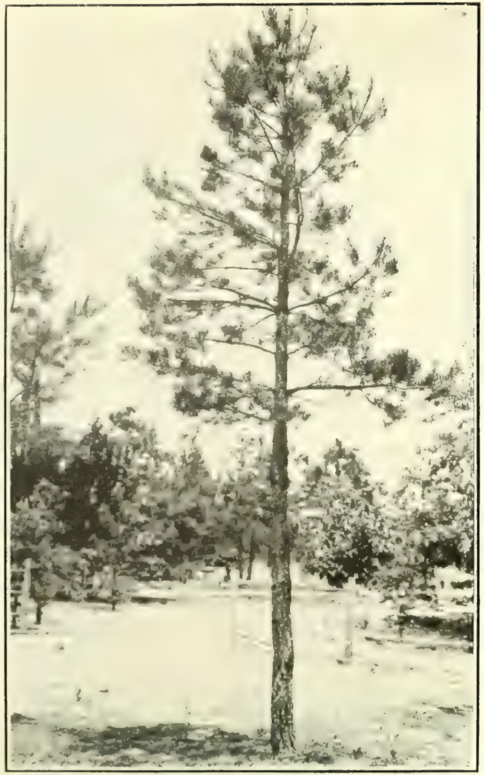

FIG. 1.—NARROW CROWN WHEN GROWN IN THE OPEN.

FIG. 2.—SIXTY-YEAR-OLD STAND OF ABOUT 300 PER ACRE.

STRAIGHT, CLEAN TRUNK AND NARROW CROWN OF SHORTLEAF PINE.

FIG. 1.—VIGOROUS 3-YEAR-OLD SHORTLEAF PINE OF SECOND GENERATION OF FIRE SPROUTS.

FIG. 2.—*a*, SPROUT OF SHORTLEAF PINE SHOWING CHARACTERISTIC DOUBLE CROOK IN TAPROOT, AND STUB OF PARENT STEM; *b*, RARE CASE OF ROOT SUCKERS OF SHORTLEAF PINE FOLLOWING INJURY TO EXPOSED ROOT BY GROUND FIRE.

FIG. 1.—SHORTLEAF PINE FIRE COPPICE 4 YEARS OLD IN FOREGROUND FROM 6-YEAR-OLD SPROUT PARENT STOCK. A FEW TREES OF THE FORMER STAND, NOW 10 YEARS OLD, ARE SEEN IN CENTER.

FIG. 2.—THRIFTY STAND OF SHORTLEAF PINE REPRODUCTION, 3-YEAR-OLD FIRE COPPICE, FROM 3-YEAR-OLD SEEDLINGS PARENT STOCK. ARKANSAS NATIONAL FOREST.

proached at about the age of 50 or 60 years on the best sites and 70 to 90 years on the poorer sites. In respect to the number of trees per acre at these ages, shortleaf somewhat exceeds longleaf and notably surpasses loblolly on similar qualities of site. At ages, ranging mostly from 175 to 225 years, natural thinning of stands, due to old age and overmaturity, goes on at a more rapid rate. This is closely associated with the incoming of the new generation and the sudden and rapid increase in numbers per acre.

The number of trees per acre in well-stocked stands decreases as the quality of the site improves. At 20 years, well-stocked stands in the Arkansas region have usually from 1,000 to 1,300 trees per acre; in North Carolina, 1,400 to 1,800; and in central New Jersey, 1,800 to 2,400. In general, this regional difference holds good for several decades; so that at 50 years well-stocked unthinned stands have approximately 300, 355, and 500 trees per acre, respectively, in the above three regions. The relation of the density to the quality of situation, both in one locality and in widely separated regions, appears to be constant and regular. The difference in densities in normal or well stocked stands in North Carolina and Arkansas is well shown by the contrast between Table 5 and Table 6.

TABLE 5.—*Number of shortleaf trees per acre in stands of different densities in Arkansas.*[1]

Age (years).	Under-stocked.	Well stocked.	Over-stocked.	Age (years).	Under-stocked.	Well stocked.	Over-stocked.
20	840	1,130	1,540	120	75	115	155
30	475	600	1,000	130	70	110	150
40	290	400	550	140	65	105	145
50	210	300	400	150	65	102	140
60	170	250	325	160	60	100	140
70	140	215	280	170	60	100	140
80	100	185	250	180	60	100	140
90	80	145	185	190	55	98	140
100	80	128	175	200	55	95	135
110	75	118	160				

[1] Based on measurements in 38 even-aged stands. The number of trees per acre vary quite widely in each case in accordance with the quality of the situation, and the numbers should be considered approximate rather than exact.

TABLE 6.—*Number of trees per acre for well-stocked shortleaf stands in North Carolina.*[1]

Age (years).	Quality I.	Quality II.	Quality III.	Age (years).	Quality I.	Quality II.	Quality III.
20	1,000	1,635	2,450	55	200	310	475
25	675	1,095	1,880	60	165	270	420
30	510	765	1,405	65	140	230	370
35	410	600	1,045	70	120	205	330
40	340	500	795	75	100	180	295
45	280	420	655	80	90	155	270
50	235	355	550				

[1] Based on measurements of 80 sample plots; area, 21.6 acres.

As a result of repeated burnings the density of natural stands is usually very variable. Occasionally second-growth stands have been protected by surrounding cultivated fields and the watchfulness and care of their owners. Such stands show striking regularity of tree density and much quicker wood production than unprotected stands, which is due to the influence of a protective mulch consisting of leaves ("pine straw"), twigs, and bark.

REPRODUCTION.

Few of the valuable pines in the United States reproduce as vigorously as shortleaf. The regeneration is accomplished by seed and by complete sprouting during the period of early life when the tree is most susceptible to severe injury. Reproduction by means of natural seeding is successful and heavy, because of the frequent and full seed crops, the lightness and short germinating period of the seed, and the high resistance of the seedling to unfavorable conditions of temporary shade and drought.

Abandoned fields and openings made by lumbering, windfall (in the tornado belt west of the Mississippi), and fires are quickly occupied by shortleaf pine. Ten representative counties in western North Carolina contain 393,670 acres of old-field stands of mostly pure shortleaf pine. This is 14 per cent of the total area, or 27 per cent of the forested area, of the counties. Such old-field stands characterize the forest lands of the upland regions from Virginia southward and westward throughout the range of the species. The extensive pineries near Lakewood, N. J., are mostly pure stands of shortleaf ("two-leaf") pine of similar origin. (Pl. II.) In mixture with the inferior pitch pine in New Jersey and loblolly pine in the lower or outer portions of the shortleaf range, it has not successfully held its former place of importance. The cause lies chiefly in the much closer utilization of the shortleaf and the resulting relatively greater abundance of seed trees of the associated species. In the southern mixed hardwood forest there has been a notable extension of the importance and commercial range of shortleaf. This has been due to the successive clearing, working, and "turning out" of fields and to the extensive ranging of hogs. The hogs consume practically all of the oak and hickory seed and at the same time prepare excellent seed beds for shortleaf pine by uprooting soil and humus in the fall of the year. Some seedlings, of course, are later destroyed by the same process. The results of these two agencies, operative for periods of 75 to 200 years, have been cumulative and have produced marked changes in the composition and density of the forest in various parts of the South.

On the National Forests of Arkansas natural reproduction is heavy except on the cool northern exposures, and the encroachment of

shortleaf pine into the oak and hickory type is particularly noticeable. Fresh openings become fully stocked usually during the first four years; and, normally, in the mixed pine-and-hardwood type, groups of pure young pine of a few prevailing age classes are numerous.

SEED.

The seed of shortleaf is very small, varying usually from 50,000 to 70,000 to the pound. The cones which produce them are among the smallest for all pines—from 1½ to 2½ inches in length. They persist on the trees for periods of about four years on vigorous shoots to seven or eight years on suppressed portions of the crown. Ripening in early autumn, the seeds fall by the middle of November and lie dormant during the winter. Germination usually takes place during March or April. In ordinary seed years the seed averages 50 to 60 per cent germination, varying quite widely below this standard in unfavorable seasons and with unhealthy or old-aged trees. One tree 280 years old had a full crop of cones bearing apparently good seed. The germinative power of shortleaf pine is retained to a large degree for several years. Seed of the 1911 seed crop, kept at ordinary living temperatures, gave 56.8 per cent germination in the spring of 1914. The seedlings, however, were apparently somewhat lower in vigor than those grown from fresh seed.

The seed of the shortleaf has some advantages over seeds of other species. A marked ability to germinate successfully in grass and leaf litter, as compared with other southern pines, has been observed.[1] This is in line with the inherent capacity of the species to thrive on the lighter upland soils deficient in soil moisture. The very small size of the seed gives it an advantage over larger seed in quickly reaching mineral soil. By means of a relatively large wing the seed is readily borne by the wind. A breeze will carry seed a distance of from 2 to 5 times the height of the tree; and strong winds will carry it from one-eighth to one-fourth of a mile.

Seed is produced both abundantly and regularly. Full crops occur at an average interval of about three years, with intermediate or partial crops almost every season. In a typical region of the Arkansas National Forest, during a period of 13 years commencing in 1901, shortleaf pine bore four full seed crops, seven partial crops, and failed entirely during two seasons.[2] The years of abundant seed were 1902, 1907, 1910, and 1913; 1903 and 1909 were blank years, and the others intermediate. Thrifty trees with good light supply begin to produce seed at about 20 years. Exceptional trees have been noted with cones at 16 years. In open or mixed forest

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[1] Proceedings of the Society of American Foresters, Vol. V, No. 1, "Loblolly and Shortleaf Pines," by W. W. Ashe.

[2] Record of seed crops determined by study of crowns in a large logging area, Womble, Ark.

stands seed is produced at intervals throughout life after about the thirtieth year. In crowded stands seed production is confined to the larger dominant trees and is deferred until about 40 years.

SPROUT OR COPPICE REPRODUCTION.

Shortleaf pine sprouts vigorously, and thus reproduces itself if killed back during the period of early life. This period fortunately is the time of greatest susceptibility to injury both by fire and various mechanical agencies. Its range over the drier uplands is coincident with a region of frequent forest fires, yet it is saved by notably abundant reproduction practically everywhere. Of the important commercial pines in the United States shortleaf alone possesses this capacity of complete reproduction.[1] A field investigation in 1912–13 showed clearly that comparatively very few seedlings reach ages of 3 to 6 years without being burned back, and that most forest stands have passed through this experience on repeated occasions.

It has been found possible, although somewhat difficult, to trace the history of most stands and determine definitely their origin, whether of direct seedling or coppice growth. Thus, the majority of all standing shortleaf timber examined in various portions of Arkansas was found to be of coppice origin. In abandoned fields fire less frequently sweeps over young stands because of the fire protection afforded by the naked soil. In spite of this, many old-field stands have suffered from at least one fire. Observation in Georgia, South Carolina, Virginia, and New Jersey showed that similar conditions exist throughout the geographical range of the species. The property of sprouting accounts for the remarkable aggressiveness of shortleaf pine over the region in the South most endangered by fire. Second-growth forests of the Piedmont and Appalachian regions have been subject to frequent fires during more than a century. As a general law, it may be stated that, in any specified locality, the proportion of shortleaf pine of seedling origin varies inversely as the frequence and general prevalence of fires. Stands of direct seedling origin are on the whole of insignificant area, because there are few localities protected against fire by natural barriers or by man. In one locality of optimum shortleaf development in Pike County, Ark., the only stands of direct seedling origin found were located in low, moist situations where burnings have been infrequent. Obviously the perfection of vigorous reproduction by coppice, though limited to early years, is of high importance in the profitable management of a forest species. Since the occurrence of a commercial coniferous forest largely of coppice origin is very unusual in any other species, a discussion of the function of coppicing, the sprouting capacity of the tree, and the way in which the sprouts are produced is of interest.

[1] Other pines which to a greater or less degree sprout when young are pitch pine (*P. rigida*), pond pine (*P. serotina*), and *Pinus chihuahuana* along the Mexican border.

EXTENT AND NATURAL LIMITATIONS.

In open-grown, vigorous stands, shortleaf successfully coppices up to about the eighth year, and in slow-growing, crowded, or shaded stands, to the tenth or twelfth years. The upper limit of size at which coppicing may take place ranges from diameters near the ground of 3 to 4 inches for vigorous individuals down to 2 to 3 inches for trees of slow growth. Thus the chief limitation seems to be age, modified by the general vigor and size of the individual stem.

Within these limits shortleaf is known to coppice repeatedly. Regions of frequent fires afford opportunities to observe the effects of repeated burning to the ground upon younger-aged stands. Figure 7 shows diagrammatically a fully stocked stand in Arkansas, composed

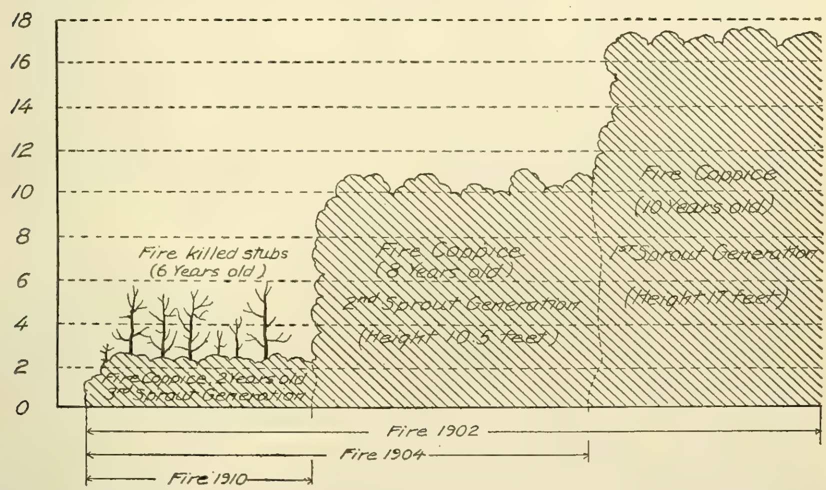


Fig. 7.—Vertical section through three successive generations of shortleaf pine fire coppice. Pike County, Ark. (Drawn from actual stand.)

of three successive generations of coppice resulting from fires in 1902, 1904, and 1910. Each age class was regular and normally stocked. The heights averaged 17 feet for the 10-year-old, 11.5 for the 8-year-old, and 2.5 feet for the 2-year-old stand. Similar successive generations of coppice are commonly met throughout all the shortleaf region. Around the margin of a young stand, surface fires burn freely, fed by the better growth of grass and light dry materials deposited by the wind; while farther within the stand there is less ground litter, and the shaded surface is often too moist to burn in the cool season when fires prevail.

The number of successive generations of sprouts that can be produced from an original parent seedling is not known. Young coppice of the second generation of sprouts is readily identified under close observation. It occurs abundantly except in old-field stands. Three

successive generations of coppice have been definitely identified; but beyond this, evidences of the past history of the tree become greatly obscured. In the third generation of sprouts the rate of height growth appears to be undiminished. Practically all of the root system is utilized by the new generation. As an effect of the root energy and stored-up food, the rate of early height growth is remarkably rapid and, within limits, increases with the age of the parent tree when cut or burned back. As a rule, during the first two to four years, depending upon the age of the parent, the sprouts make up completely for the previous loss of time in growth. The most rapid height growth observed was in a 4-year-old fire sprout stand, many trees being from 5 to 8 feet in height and the tallest 9.6 feet. The growth in height of thrifty stands of fire coppice, based on measurements of both trees and whole stands up to 18 years old, is shown in Table 6. The age at which trees of sprout origin grow at approximately the same rate as seedling trees is not precisely known. Under average conditions this point is perhaps between the fifth and ninth years. In general, the great acceleration in growth in fire sprouts takes place at approximately the same rate in diameter and volume as in height.

CAUSE AND METHOD.

Fire and cutting are the chief external causes for the sprouting of shortleaf pine. The physiological cause lies in the capacity of shortleaf pine to develop on the upper portion of the root and lower portion of the stem special reproductive buds, at least one of which has the same function as the central terminal bud on the stem.

The double crook, at the upper end of the taproot of shortleaf pine, characteristic of and always present in young trees, seems to be intimately associated with its power of reproduction by sprouts. By means of this double crook a horizontal section from 1 to 3 inches in length, varying with the age, is formed at the upper end of the taproot. This form persists during the first 8 to 12 years, after which its identity becomes lost through the increasing thickness of the annual accretions. It is significant that the capacity for sprouting is coincident with the period during which the root maintains this characteristic form. During this period adventitious stem buds are present and may readily be seen along the horizontal section of the root. The corky bark here is unusually thick, affording a high degree of protection against ordinary fires.

The killing of the stem is followed by the development of a colony of sprouts at the base of the stem and top of the taproot, usually from 6 to 12, as shown in figure 8, and not infrequently 16 to 20. Normally one stem (occasionally two) assumes the function of leader, the others being more or less procumbent in habit and serving as laterals or

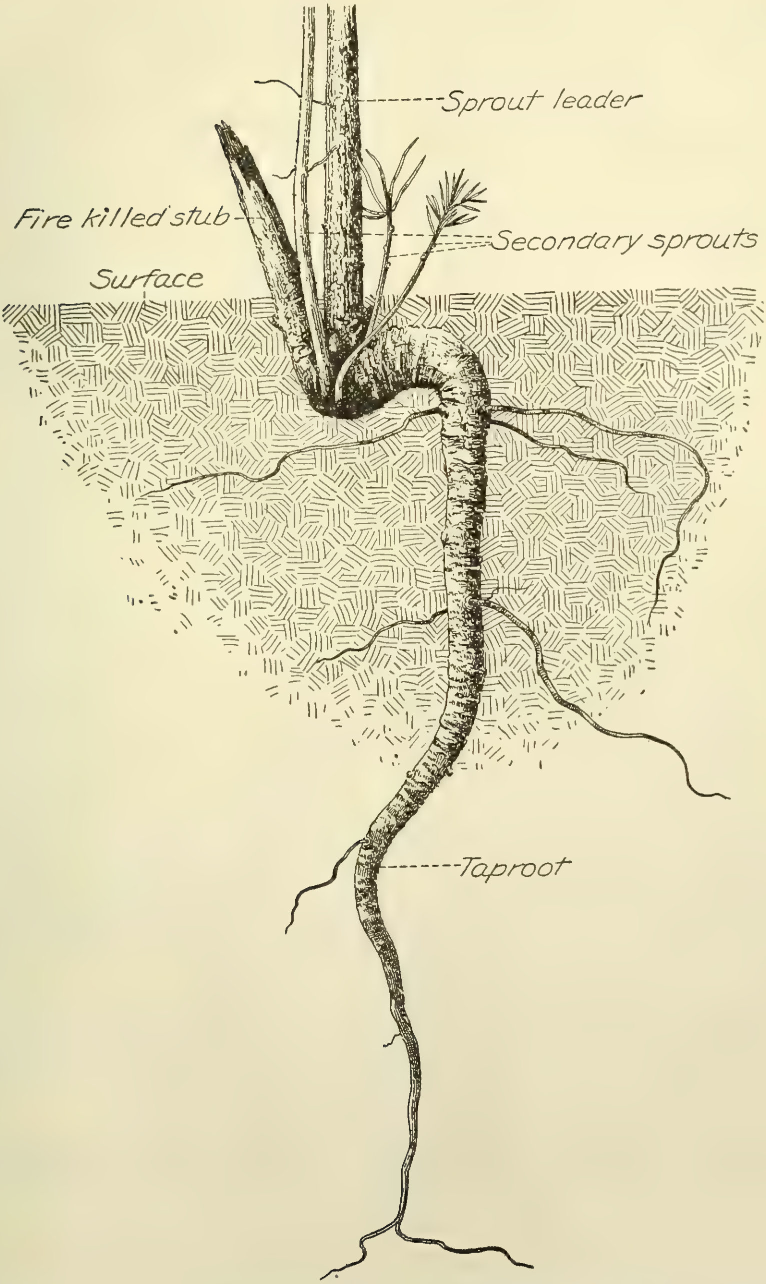


FIG. 8.—Sprout shortleaf pine following fire, showing new upright stem, secondary sprouts, or "laterals," and characteristic crook of the taproot. Three-year-old coppice from 7-year-old seedling parent. (Drawn from actual specimen.)

feeders. In the organization of the sprout colony, the correlation of the two classes of vegetative buds of the tree is thus carried out. In producing normally a single new upright stem, shortleaf resembles the hickories, in contrast to the oaks and chestnut, which commonly mature several main stems. In open situations and understocked stands a tendency to develop twin stems is sometimes seen in vigorous stands of shortleaf. A tendency to increase the number of stems above two appears to be caused directly by unfavorable factors of age, weakness of the parent, poor light supply, or climatic conditions. For example, as many as 42 coordinate upright stems have been counted on a stump 4 inches in diameter, cut in midsummer. In coppice stands up to 50 years old, a few twin trees will usually be found. The oldest tree of undoubted sprout origin observed was 226 years.[1]

TABLE 7.—*Height growth of dominant shortleaf pine in pure, well-stocked stands of fire coppice origin.*[1]

Age (years).	Height (feet).	Age (years).	Height (feet).
1	1.3	10	18.3
2	2.7	11	20.6
3	4.2	12	23.3
4	5.8	13	26.0
5	7.5	14	28.8
6	9.5	15	31.7
7	11.6	16	34.7
8	13.9	17	37.9
9	16.1	18	41.0

[1] Based on 100 individual trees and the average trees for 8 sample plots 9 to 18 years.

An 18-year-old coppice stand, near Glenville, Nevada County, Ark., averaged 248 trees per acre. Of these, 71 trees had two stems each, 7 had three stems, and 1 had four stems, or a total of 336 stems per acre. Thus 33 per cent of the trees had more than one stem. The sprout origin of the stand was completely identified, but there is no record whether the cause was fire or chopping to clear a pasture. The stand was vigorous and averaged 44 feet high. The average diameters of all stems was 6.3 inches, while that of the trees proper, or each tree colony taken as a unit, was 7.4 inches. Three colonies of twin trees and some single stems are shown in Plate V.

[1] A large twin-stemmed tree with single root system exposed by erosion on a stream bank. There were others of nearly the same size and form in the same stand.

TABLE 8.—*Number of trees per acre and number of tree stems per acre in 18-year-old coppice shortleaf stand, Nevada County, Ark.*

Diameter breast high (inches).	Trees per acre.[1]					Total stems per acre.
	Stems per tree colony.				Total.	
	1	2	3	4		
2	6				6	6
3	28	1			29	30
4	24	8	3	1	36	53
5	9	27	3		39	72
6	28	18	1		47	67
7	27	10			37	47
8	34	5			39	44
9	6	2			8	10
10	6				6	6
11	1				1	1
Total	169	71	7	1	248	336

[1] Individual trees with one or more stems, as the case may be.

As a result of the tree's vigorous coppicing during early life, shortleaf occurs characteristically in even-aged stands. A fire after 6 to 8 years reduces to a single age class all the several ages of young growth that may have come in during the period. This has been found to be the case in all of the regions studied. It is significant in this connection that in one region of abundance and good development of shortleaf,[1] two age classes strongly predominated throughout the whole stand. One group consisted of pure stands from 160 to 180 years old and the other of similarly pure stands from 60 to 70 years. The average between the two groups is 105 years. This may be looked upon as indicating the occurrence of periods of either tornadoes or unusually destructive crown fires. The 60-year-old age class is especially abundant over the region. Old local records may possibly confirm this supposition of some unusual occurrence of the sort indicated between the years 1848 and 1852.

SEASON OF YEAR.

In common with the broadleaf species, the sprouting takes place least actively following midsummer cutting. Pastures and rights of way are thus commonly treated. In one instance a pasture contained a good stand of vigorous shortleaf-pine sprout saplings, 4 years old and from 6 to 10 feet high, representing the third generation of coppice from winter or early spring cutting. Along railroad rights of way in the Arkansas region, it is common to see dense sprout thickets of shortleaf pine due to repeated mowing. The forest-fire season occurs during the fall and late winter. This is during the period of vegetative inactivity, and such burnings generally result in vigorous sprout growth the following spring.

[1] Montgomery and Pike Counties in western central Arkansas.

METHOD OF DETERMINING SPROUT ORIGIN.

Determination of the sprout origin of shortleaf pines during early life is possible by means of external characteristics. The presence of a colony of two or more living stems, also the presence of dead stems or stubs of the parent tree (charred in the case of fire), and the large size of the sapling or pole in relation to its age are clear evidence of coppice origin. A clean, smooth base without scars or adjacent stubs indicates seedling origin. This evidence is sufficient and dependable up to about the eighth year. Dead stems from 2 to 5 feet high, when killed by fire, will ordinarily be found standing at the end of the third year. In very early life sprout stands may be found to contain a considerable number of twin and triple colonies, but the number decreases rapidly with advance in age. In the latter stands,

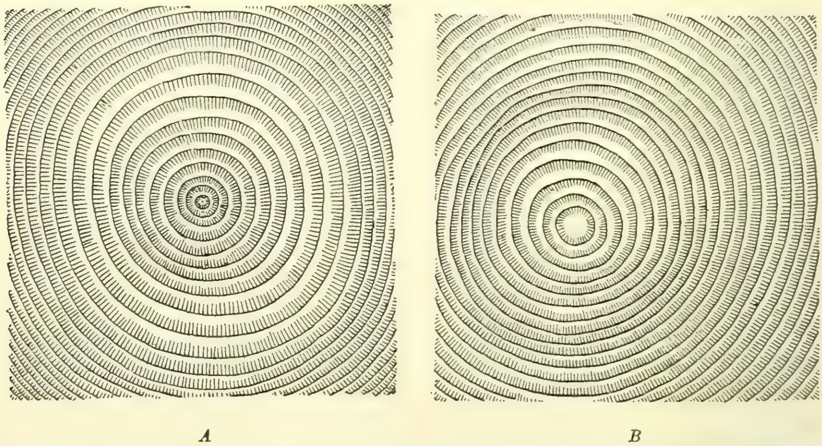


FIG. 9.—Determination of origin of shortleaf pine by basal sections at the ground: *A*, Tree of seedling origin; *B*, coppice tree 64 years old. Diameter of core, or first year's growth, is 3 times and cross-section area 8.9 times that of tree (*A*) of seedling origin. (From photographs.)

trees are frequently seen with dead or dying stems, forked at an acute angle or emerging from their sides, at distances a few feet above the ground. Following the first 6 to 10 years no external characteristics are usually apparent except occasionally multiple living stems.

The first year's stem growth of trees of seedling origin is about as thick as a darning needle and 2 to 4 inches high, while the corresponding growth of young coppice sprouts is commonly as large as an ordinary lead pencil in diameter and about double its length. (Fig. 9.) The following few years' growth in each case is on a proportional scale. Thus the character of early growth, particularly that of the first year, recorded in the base of the tree and visible when the tree is cut level with the ground, affords a dependable record of the origin of the tree. Coppice trees, furthermore, usually have some of the dead stubs of

the former generation embedded at their bases. (Fig. 10.) In most cases fire has been the cause of the sprouting, and since both the inclusion of charred stubs and the size of the core can readily be ascer-

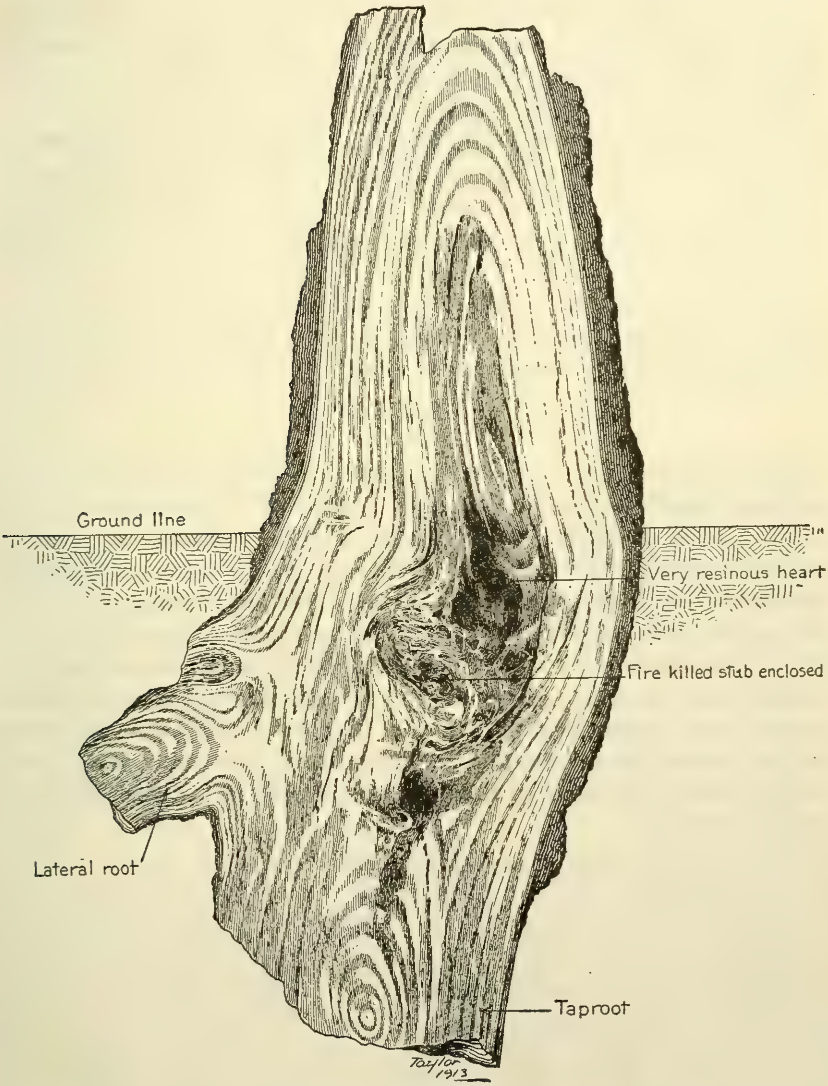


FIG. 10.—Vertical section through base of 18-year-old, thrifty shortleaf pine of coppice origin, inclosing stub of parent stem. (From photograph.)

tained, if present, by an examination of the extreme base of the tree, these marks embedded similarly in a number of trees selected at random will serve to confirm the coppice origin of the whole stand. An indication of origin may be seen in low-cut stumps [1] in logging

[1] In Arkansas 6 to 9 inches high for small trees and 1 foot for the larger ones are customary heights.

areas, the core of coppice being composed of large conspicuous rings in contrast to the small rings of seedling trees.

ECONOMIC VALUE.

Fire as a menace to young pine in great measure prevents capital from going into what otherwise appears to be a paying investment. White pine in New England is a well-known example. The case is somewhat different with shortleaf, in which practically the only fire loss is from exceptionally hot fires which destroy large saplings or pole stands too large to sprout. Repeated burning in the dormant seasons of the year, when almost all fires occur, seems to offer no appreciable setback for at least three sprout generations. Therefore the element of fire risk in the production of all important eastern coniferous species is reduced to the minimum in shortleaf pine by its vigorous sprouting habit. This feature highly recommends the species for profitable managment throughout its range.

GROWTH.

HEIGHT.

The long growing season throughout most of its range and its inherent vigor make shortleaf pine a tree of rapid height growth. In situations of equal favorableness it is more rapid than longleaf pine and only slightly less so than loblolly pine. On average upland soils typical of most of its range it excels its most common associates among the oaks and hickories. In Arkansas and adjacent States, on the better sites bigbud and bitternut hickories are distinctly below it, yellow and Spanish oaks nearly equal it, and sweet gum slightly exceeds it in height growth. In the Piedmont and Arkansas regions height growth is not widely different on similar qualities of site. Table 9 shows the rate of growth and relation of heights to age for the two regions.[1]

TABLE 9.—*Height growth of shortleaf pine, based on age, in Arkansas and North Carolina.*[2]

WESTERN ARKANSAS.

Age (years).	Height.			Age (years).	Height.		
	Maximum.	Average.	Minimum.		Maximum.	Average.	Minimum.
	Feet.	*Feet.*	*Feet.*		*Feet.*	*Feet.*	*Feet.*
20	51	45	37	90	79	73	67
25	56	50	43	95	80	74	68
30	59	54	48	100	81	74	68
35	62	57	52	110	83	76	69
40	64	60	54	120	85	77	70
45	66	62	57	130	87	78	71
50	68	64	59	140	88	79	71
55	69	65	60	150	89	80	71
60	71	66	62	160	90	81	72
65	72	67	63	170	91	81	72
70	74	69	64	180	92	82	72
75	75	70	65	190	93	82	72
80	76	71	65	200	93	83	73
85	78	72	66				

[1] Table 7 shows the height growth of shortleaf known to be of coppice origin.
[2] The Arkansas table is based on age-height measurements of 285 trees and diameter-height of 3,214 trees; the North Carolina table is based on age-height measurements of 332 trees and diameter-height of 384 trees.

TABLE 9.—*Height growth of shortleaf pine, based on age, in Arkansas and North Carolina*—Continued.

PIEDMONT REGION, NORTH CAROLINA.

Age (years).	Height.			Age (years).	Height.		
	Maximum.	Average.	Minimum.		Maximum.	Average.	Minimum.
	Feet.	*Feet.*	*Feet.*		*Feet.*	*Feet.*	*Feet.*
5	22	13	....	45	75	67	40
10	48	29	10	50	76	68	43
15	63	42	15	55	76	69	45
20	69	50	20	60	77	69	48
25	71	57	25	65	77	70	49
30	73	61	29	70	77	70	51
35	74	63	33	75	78	70	53
40	75	65	36	80	78	71	55

During early life the terminal leader of shortleaf pine commonly forms from two to four secondary or false terminal nodes during the growing season. These are accompanied by false rings of growth in the wood, usually plainly marked and apt to be mistaken for true rings.

The influence of side light upon height growth is well illustrated in figure 5, showing a 10-year-old stand of shortleaf with the east and west side light cut off by an adjacent stand. The heights increase from 2 feet near the margin to 22 feet under full light. This illustrates very well the need of light for development, and, at the same time, the power of endurance of shortleaf under limited light supply. A 9-year-old stand with 3,800 trees per acre averaged 19 feet high as compared with only 16 feet for a near-by stand of the same age and on similar soil with 12,200 trees per acre. Two adjacent young stands, similar in all points except tree density, averaged 9 feet high for 4,100 trees per acre and 5 feet high for 32,000 trees per acre.

DIAMETER.

The rate of diameter growth of shortleaf pine is intermediate between that of loblolly and that of longleaf pine, the slowest of the important southern pines. Besides the well-defined annual rings of wood which clearly record diameter growth, from two to four terminal nodes in the stem of the tree, accompanied by slight resting periods in the tree's activity, usually occur during the period of vigorous growth in earlier life. These growth periods are recorded by fine lines of denser wood within the true annual rings. Periods of injury, caused by insect attack, fire, or severe drought during which growth is temporarily checked, usually have the same effect. Such lines, forming false rings, are frequent in shortleaf pine, and must be distinguished in examining a cross section for age. Prominent bands of wood stained brown in color are particularly apt to be found in

young shortleaf and erroneously mistaken for true annual rings of growth.

Diameters throughout this bulletin, unless otherwise stated, are measured at breast height (4½ feet above the ground). Table 10 shows the diameter growth based on age for the Piedmont region of North Carolina and for western Arkansas. The tables may be considered as broadly applicable to large areas within the two specified regions, since differences in growth over large areas are not important except as caused by local variation in quality of situation.

TABLE 10.—*Diameter growth of shortleaf pine, on the basis of age, in Arkansas and North Carolina.*[1]

WESTERN ARKANSAS.

Age (years).	Diameter breast high.			Age (years).	Diameter breast high.		
	Maximum.	Average.	Minimum.		Maximum.	Average.	Minimum.
	Inches.	*Inches.*	*Inches.*		*Inches.*	*Inches.*	*Inches.*
20	7.2	5.7	4.3	90	18.5	15.9	13.3
25	8.6	7.0	5.4	95	19.0	16.3	13.6
30	9.9	8.1	6.4	100	19.4	16.6	13.8
35	11.0	9.1	7.4	110	20.3	17.3	14.2
40	12.0	10.1	8.2	120	21.1	17.8	14.6
45	12.8	10.9	9.0	130	21.7	18.3	14.9
50	13.6	11.7	9.7	140	22.3	18.7	15.1
55	14.4	12.3	10.3	150	22.8	19.0	15.3
60	15.1	12.9	10.8	160	23.2	19.3	15.4
65	15.7	13.5	11.3	170	23.6	19.6	15.5
70	16.3	14.0	11.8	180	23.9	19.7	15.6
75	16.9	14.5	12.2	190	24.1	19.9	15.7
80	17.5	15.0	12.6	200	24.3	20.1	15.8
85	18.0	15.5	12.9				

PIEDMONT REGION, NORTH CAROLINA.

5	2.0	0.9	....	45	17.1	10.5	4.5
10	5.9	3.0	0.6	50	17.6	11.0	5.0
15	9.2	4.9	1.2	55	18.0	11.4	5.4
20	11.6	6.3	1.8	60	18.4	11.7	5.8
25	13.3	7.5	2.4	65	18.7	12.1	6.1
30	14.5	8.4	3.0	70	19.0	12.4	6.4
35	15.6	9.2	3.5	75	19.2	12.7	6.8
40	16.5	9.9	4.0	80	19.4	13.0	7.1

[1] The table for Arkansas is based on breast-high diameter measurements of 285 trees and 34 trees representing the average of even-aged plots; the North Carolina table is based on decade measurements on 332 stumps, 26 to 89 years old.

The close relation between tree density and growth in diameter is illustrated in Table 11, compiled from measurements on unit areas of different density of trees of a 30-year-old fully stocked shortleaf stand. In seven consecutive sample areas of one-tenth acre each, the size of the diameter class prevailing on each plot increased regularly with a corresponding regular decrease in the number of trees per acre. So far as is known this close relation holds true for all pure stands of shortleaf pine.

TABLE 11.—*Relation of tree density and diameter growth in 30-year-old pure stands of shortleaf of varying densities, Arkansas National Forest.*[1]

Prevailing diameter class (inches).[2]	Tree density (trees per acre).	Decrease (trees per acre).	Prevailing diameter class (inches).[2]	Tree density (trees per acre).	Decrease (trees per acre).
4	800		8	475	85
5	720	80	9	390	85
6	640	80	10	300	90
7	560	80	11	210	90

[1] Based on seven plots in the same stand of varying density, but having uniform soil conditions.
[2] The diameter class having the largest number of trees in the individual stand.

VOLUME GROWTH.

The merchantable contents of a tree obviously depends upon total height and diameter taken at successive points along the stem. The rise in percentage of the rate of increase in the volume of shortleaf pine in common with most trees culminates at a comparatively early age, considerably prior to the year of maximum production of wood for the individual tree. Furthermore, the highest annual production of wood is reached somewhat earlier than the production of saw timber. In stands of relatively equal density those on the poorer sites and near the margin of natural distribution reach the maximum rate of volume production at a later age than similar stands on more favorable sites and more centrally situated within the region of distribution. For example, the individual trees in stands in Missouri, West Virginia, and New Jersey apparently show the greatest annual wood increment at about 70 years, but in North Carolina the culmination is reached at about 50 years, and in Arkansas at about 35 to 40 years.[1] The contents in board feet and cubic feet of trees of different ages, up to 80 years, for two qualities of site, are shown in Table 12.

TABLE 12.—*Volume of shortleaf pine in North Carolina, based on age for two site classes.*

[Based on diameter growth of 332 trees, and volume table. Stump height, 1 foot for trees 6 to 16 inches; 1.5 feet for trees 17 inches and over.]

Age (years).	Saw timber.				Solid contents.[2]	
	Scribner rule.		Doyle rule.			
	Quality I.	Quality II.	Quality I.	Quality II.	Quality I.	Quality II.
	Board feet.	*Board feet.*	*Board feet.*	*Board feet.*	*Cubic feet.*	*Cubic feet.*
15	51		17		13.5	
20	100	6	50	3	24	2.6
25	147	23	87	7	34	6.7
30	186	38	125	11	43	10.3
35	221	51	160	17	50	13.8
40	251	63	191	24	56	16.7
45	275	75	216	32	61	19.3
50	296	86	237	39	65	22.0
55	315	96	255	46	69	24.0
60	331	105	271	53	72	26.0
65	345	113	284	60	75	28.0
70	357	121	295	66	78	29.0
75	369	129	306	73	80	31.0
80	381	135	316	79	82	32.0

[1] For volume tables of shortleaf pine based upon height and logs per tree, see a forthcoming bulletin on the Importance and management of shortleaf pine.
[2] Total volume of stem, including bark, between stump and top diameter, outside bark, of 5.5 inches.

RECOVERY AFTER SUPPRESSION.

Shortleaf pine possesses to a high degree the ability to recover after suppression. This feature is well exhibited in a rapid increase in diameter growth following an increase in the supply of light. Events of any sort which produce changes in stand densities are recorded in quite a remarkable manner by shortleaf pine.

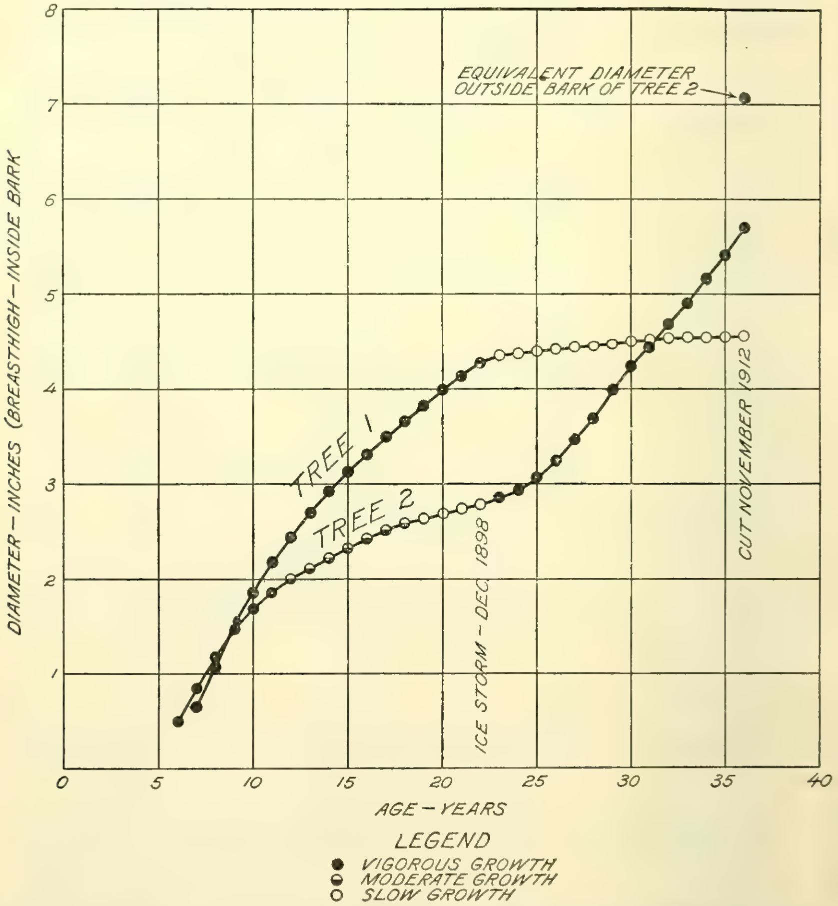
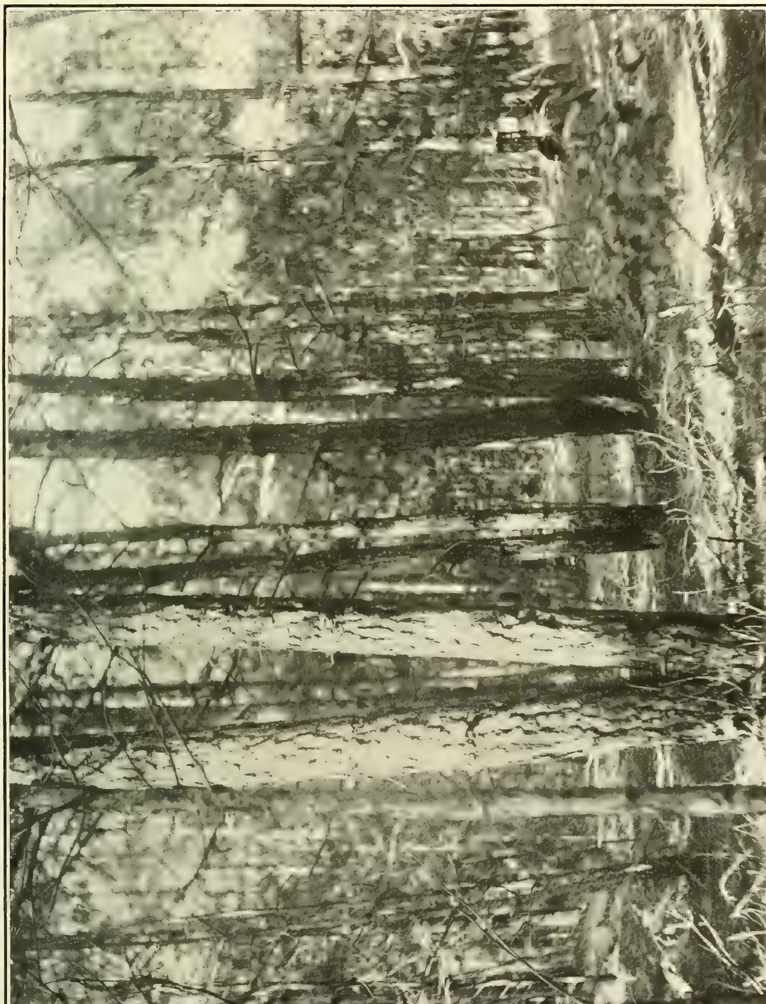


FIG. 11.—Effect of an ice storm upon subsequent diameter growth in a 22-year-old crowded shortleaf stand. Tree 1, formerly dominant, permanently bent over by ice and suppressed for a period of 14 years; tree 2, formerly partially suppressed, given more light by the storm, vigorous and dominant for the past 14 years.

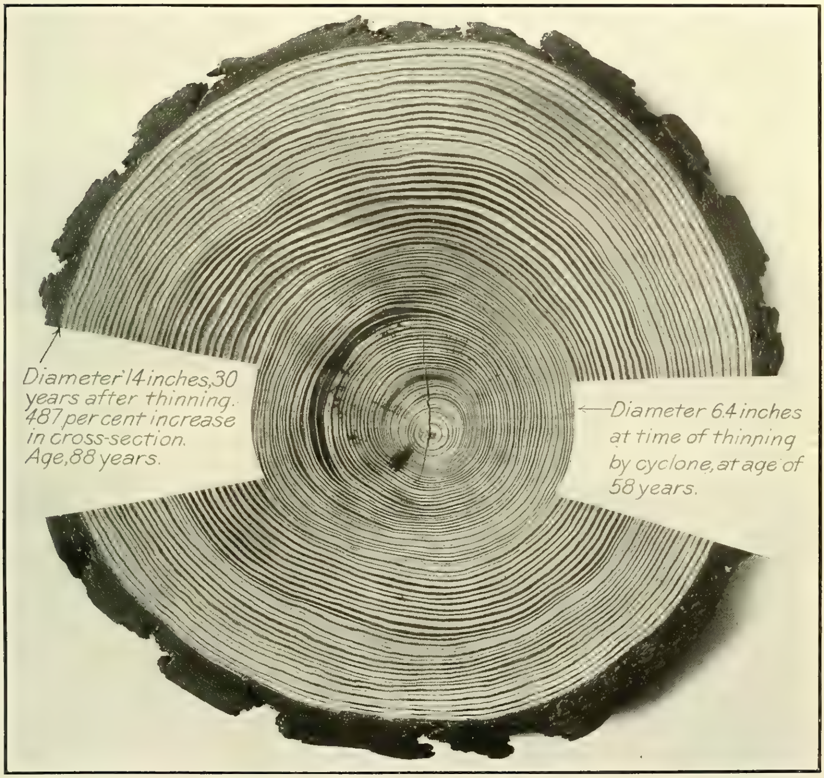
The effect of a heavy ice storm upon a thrifty 22-year-old fully stocked stand in Nevada County, Ark., as recorded by the diameter growth, is seen in figure 11 and Plate VIII. The storm occurred in December, 1898, and the stand in 1912 was 36 years old. The heavy ice bent over many of the larger-crowned, dominant trees, thereby opening up many smaller-crowned, middle and lower class trees.



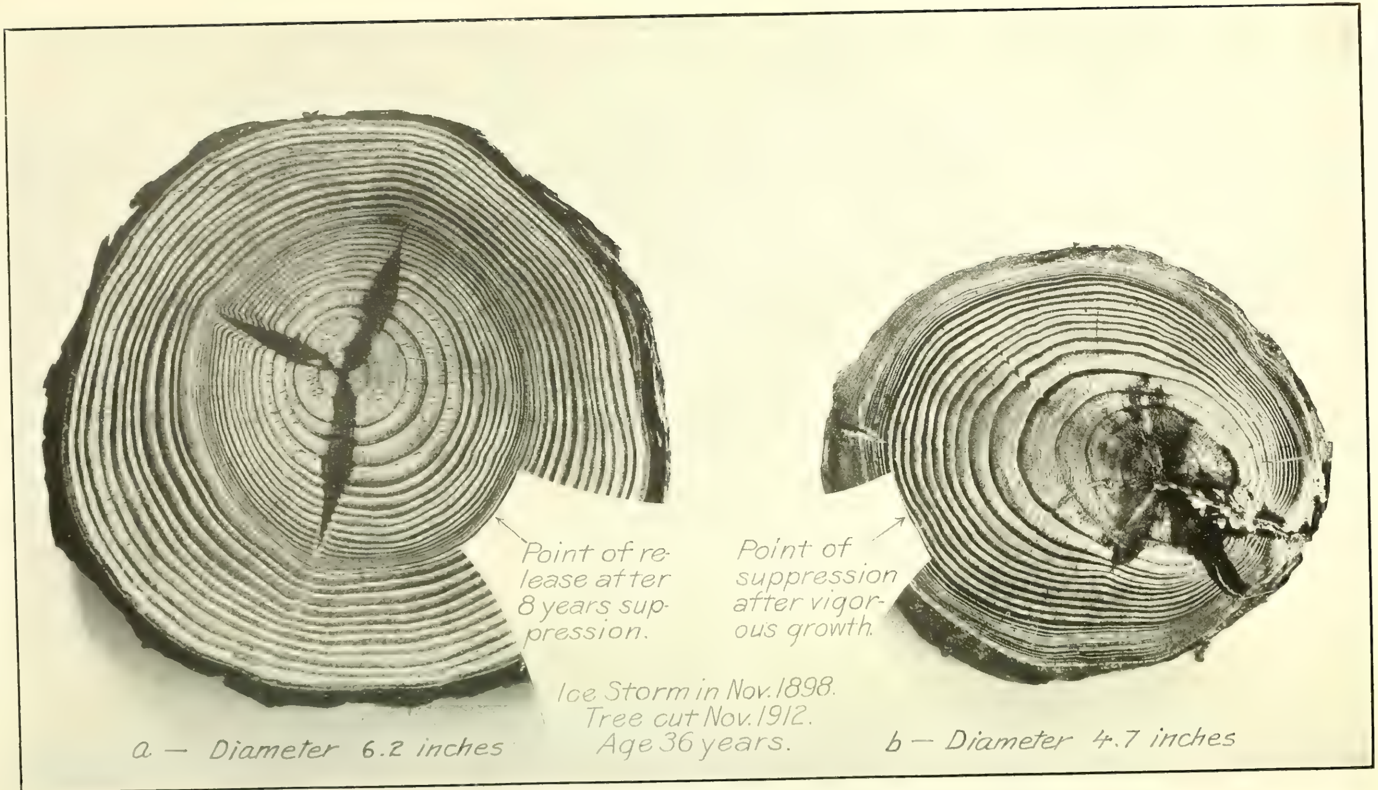
COPPICE STAND OF SHORTLEAF PINE 18 YEARS OLD.

Thirty-three per cent of the trees have more than one stem. Dominant trees are 6 to 11 inches breast-high diameter. Nevada County, Ark.

SECTION THROUGH BASE OF 65-YEAR-OLD TWIN SHORTLEAF PINE OF SPROUT ORIGIN.



RAPID RECOVERY OF SHORTLEAF PINE AFTER SUPPRESSION. EFFECT OF NATURAL THINNING BY TORNADO, 31 YEARS AGO, UPON TREE 58 YEARS OLD. ARKANSAS NATIONAL FOREST.



EFFECT OF NATURAL THINNING BY ICE STORM. SECTIONS OF ADJACENT TREES.

a, Tree formerly suppressed now vigorous and dominant; *b*, tree bent over and permanently suppressed by ice storm.

FIG. 1.—EFFECT OF NANTUCKET TIP MOTH (LEFT) ON 8-YEAR-OLD COPPICE SHORTLEAF. TREES SAME AGE AND HEIGHT AT OPENING OF SEASON.

FIG. 2.—EFFECT OF ICE STORM AFTER A LAPSE OF 14 YEARS.

INJURY BY INSECTS AND HEAVY STORMS.

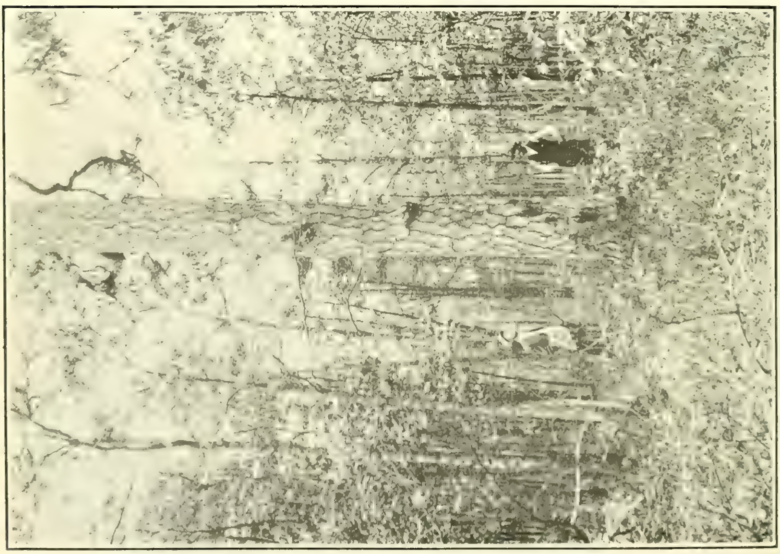


FIG. 1.—BADLY DISEASED SHORTLEAF IN NEW JERSEY.

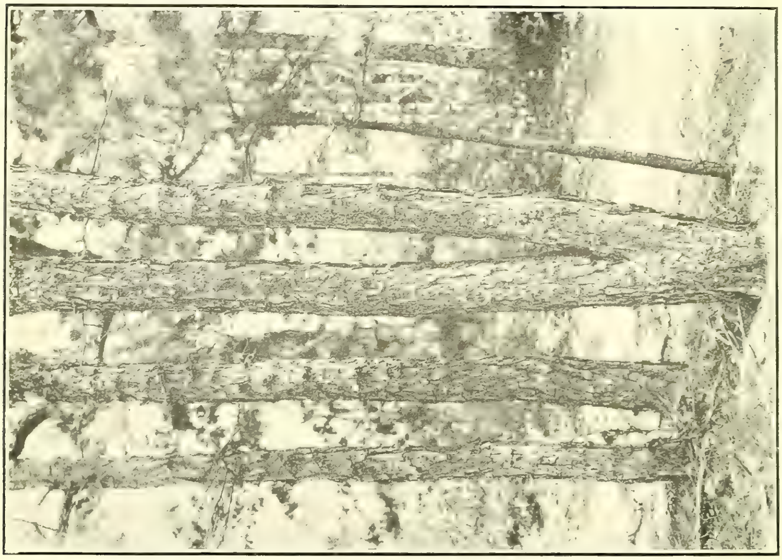


FIG. 2.—EFFECT OF FIRE IN CAUSING FORKED STEMS. NEW JERSEY.

INJURY FROM FUNGI AND FIRE.

The storm lasted for nearly a week and many of the bent trees which were given a permanent "set" were alive after 14 years of suppression. The record of interchange of crown classification and resultant growth is well illustrated in the breast-high sections of two representative trees shown in the illustration. In the 10-year period following the storm, the tree suppressed by the ice changed from 97 per cent to 13 per cent rate of diameter growth, while an adjacent and formerly partly suppressed tree showed, as a result of the opening up, an increase of growth from 65 to 122 per cent.

An immediate response in diameter growth at the age of 58 years is exhibited in Plate VII, showing a representative tree opened up 31 years prior by a tornado in Montgomery County, Ark. As a result of this natural thinning the growth averaged 8 rings to the inch for the 30 years following as compared with 16 rings per inch for the 30 years preceding the natural thinning. The increase in basal area

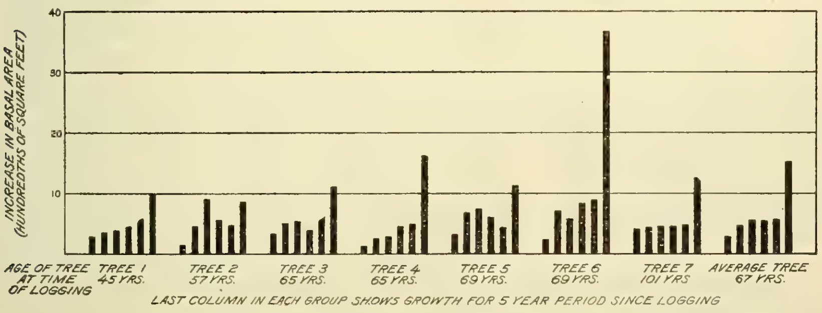


FIG. 12.—Increased rate of growth of 7 representative shortleaf pine trees on a typical cut-over tract, cut 5 years ago. Growth in basal area at breast height, for successive 5-year periods, during the past 30 years.

was 487 per cent during the latter period. The immediate recovery is shown by the increase during the first season. The tornado made a clean sweep along the center, about one-half mile in width, and a thinning of decreasing degree toward the margin of its path, which was about 14 miles in length.

The ability of a species to recover from suppression can be ascertained by a study of cut-over areas following logging operations. The stimulation in growth of shortleaf pine on a typical cut-over tract, logged to an approximate minimum stump diameter of 14 inches[1] 5 years prior to the examination, is shown graphically in figure 12, based on Table 13. The increase in basal area during the five years following logging is contrasted with the increases for the five preceding five-year periods. Practically all trees observed showed stimulated growth due to thinning and increased light supply. Trees formerly suppressed, however, grew relatively much faster after the logging. The least gain

[1] Hellbig, Ark., near the Arkansas National Forest, logged in 1907 and examined in 1912.

in basal area at breast height was 75.4 per cent, the largest 311 per cent, and the average for 7 representative trees was 171.4 per cent over their former rates of growth. The trees ranged from 45 to 101 years old at the time of the logging, but most of them were between 60 and 70 years. Since height growth was mainly complete at this age, it is perfectly safe to say that the volume increment of the trees took place at approximately the same or possibly at a somewhat greater rate, because of the greater increase in the size of the upper part of the stem at this age.

TABLE 13.—*Comparative growth of shortleaf in five-year periods before and after logging.*[1]

Tree No.	Age at time of logging.	Increase in basal area (breast height).						
		Five-year periods prior to logging.					Five-year period after logging, 1908–1912.	Rate of increase since logging over previous five-year periods.
		1883–1887	1888–1892	1893–1897	1898–1902	1903–1907		
		Sq. in.	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Per cent.*
1	45	4.2	4.9	5.6	6.5	8.2	14.4	75.4
2	57	2.0	6.2	13.0	8.1	6.8	12.4	83.0
3	65	4.6	7.2	7.8	5.6	8.8	15.8	80.3
4	65	1.7	3.6	3.9	6.3	6.9	24.0	247.9
5	69	4.5	9.5	10.5	8.6	6.0	16.1	166.6
6	69	3.2	10.1	8.2	11.8	12.8	52.7	311.2
7	101	5.8	6.0	6.3	6.5	6.8	18.0	165.9
Average	67	3.7	6.8	7.9	7.6	8.0	21.9	171.4

[1] Typical shortleaf stand cut 5 years ago to an approximate diameter limit of 14 inches in average quality site in western Arkansas.

CAUSES OF INJURY.

FIRE.

The damage to forest growth caused by fire far exceeds the combined effect of all other injurious agencies. At the same time, this cause of injury is the most susceptible to control of man. The annual burning of the forest floor, extensively practiced in the past throughout the shortleaf region, has been done with little realization of the damage to the forest. Shortleaf which has passed the earlier stages suffers much permanent injury from fire. Abundant seeding, low resin content of the wood, and early rapid height growth, in addition to sprouting, afford shortleaf perhaps the best chance of any of the important southern pines to survive under adverse conditions caused by fire, but in spite of these favorable characteristics much loss and injury occur.

Completely stocked stands of shortleaf over 20 years in age are rarely found in tracts of considerable size, except in old fields and in other situations where fire has been practically excluded. As a rule, the stand is irregular in density, with many small openings, for which

fire is chiefly responsible. The heaviest direct injury to the stand occurs just after the ages of 8 to 12 years, because prior to this time the young forest is quickly restored by its power of coppicing. Repeated burnings, however, cause a setback which the tree is able to make up only in part. In older trees the effect of frequent fires is cumulative in weakening the tree at its base, resulting in its overthrow during high wind. Although not so complete in the case of shortleaf as in that of the more resinous longleaf, the sort of decimation of stands is continuous and rapid where fire occurs frequently. External injury and loss in vitality, due to excessive heat, open up avenues of ready attack by insects and fungi.

Ordinary surface fires usually develop sufficient heat to kill back trees up to 6 or 8 feet in height, and to injure trees from about 7 to 12 feet in height. Basal fire scars heal rapidly, and during intervals between fires thrifty pole and standard trees usually succeed in completely covering them. Such cases are quite frequently noted in examining the tops of stumps. The damage and loss due to fire is mainly in the form of defective lumber and reduced yield per acre from the stand, which may be ascertained by measuring the yields from well-stocked groups selected within a stand and comparing them with its total yield. The wide difference between the two is perhaps the most impressive measure of the beneficial effect of protection, since fire can safely be considered one of the most active causes of the poorly stocked condition of our forest stands.

INSECTS[1] AND MAMMALS.

Of all insects, the southern pine beetle (*Dendroctonus frontalis* Zimm.) is undoubtedly the most injurious to shortleaf pine. It is active throughout the warmer portions of the year, passing through the bark to the cambium, or living layer, and there eating out long, winding furrows or egg galleries, which partially girdle and weaken the tree. The eggs hatch into grubs, which feed on this tissue, completing the girdling and destroying the tree. Serious invasions of this insect occurred in 1890, 1893, and 1910. The last outbreak led to a special study by the Bureau of Entomology, whose report,[2] describing fully its life history and giving recommendations for controlling the insect pest, may be obtained upon application to the Division of Publications, Department of Agriculture, Washington, D. C. It has been demonstrated that using trees that die in the fall and early winter for fuel or other purposes during the winter serves both to control the beetle and to prevent its outbreak. This is an important point to bear in mind in handling shortleaf stands.

[1] For further information in regard to causes of injury by insects, apply to the Office of Insect Investigations, Bureau of Entomology, U. S. Department of Agriculture.

[2] Farmers' Bulletin 476, "The Dying of Pine in the Southern States: Cause, Extent, and Remedy," U. S. Department of Agriculture. Also, Bureau of Entomology Bulletin 83, Part I, "Bark Beetles of the Genus Dendroctonus," by Dr. A. D. Hopkins, p. 56.

The Nantucket pine-tip moth (*Retinia frustrana* Scud.) attacks and deforms the rapid-growing tips of branches. The attack of this insect is locally the most perceptible injury, but the insect is not a serious menace. The presence of dead tips and pitch exudations are the characteristic external signs of the attack, usually equally present on other pines, for the insect is widely distributed and attacks without apparent discrimination practically all pines. As a rule, the insect is not abundant for more than one or possibly two years. By virtue of its high vigor and its capacity for forming new shoots, shortleaf pine recovers rapidly after an attack, suffering mainly the loss of time during the period of arrested growth.

Trees cut or thrown during the summer months soon become infested with larvæ of the southern pine sawyer, or borer, known commonly as a "flathead."[1] The larvæ of this genus, *Monohammus*,[2] hatched from eggs laid under the bark, feed on the rich sapwood, but seldom penetrate to the heartwood. They never attack living trees in the South. Rapid drying of the logs is the surest prevention; so that trees cut in the summer months should be removed from stands to dry situations exposed to sun and wind, or barked and opened up fully. Immersion in water where possible is the simplest remedy.

Mice, chipmunks, squirrels, and birds are very destructive of seed, and, to some degree, of seedlings. The abundant production of seed, however, accounts for the plentiful regeneration of shortleaf in spite of these enemies. On account of the small size of the seed, hogs destroy little or none directly, and they cover many in the process of rooting, so that the hog is to be looked upon rather as a benefit than a menace to the shortleaf forest. In mixed pine and nut-bearing forests, the presence of the hog is decidedly favorable to the regeneration of pine through the destruction of the hardwood seeds. In artificial forestation, mammals and birds are always one of the chief sources of injury, because they destroy large quantities of seed.

FUNGI.

The southern timber pines as a group are not badly infested with timber-destroying fungi until advanced in age or well past maturity. Up to 100 years of age, shortleaf pine is remarkably low in susceptibility to fungus attack; above this age, and especially after the age of about 150 years, in regions subject to frequent fires, fungi are more prolific and more easily gain a foothold in the tree.

Three species of fungi are more or less common in shortleaf pine and cause nearly all of the wood rot commonly known as "redheart."[3] Two species of fungi, *Polyporus schweinitzii* and *Polyporus sulphureus*, enter the tree through wounds on the butt or on the stool of

[1] The insect is really a roundheaded borer, and not a member of the flat-headed group.

[2] Chiefly, *Monohammus titilator* Fab. See Bureau of Entomology Bulletin 58, "Some Insects Injurious to Forests," p. 41.

[3] Long, W. H., Office of Forest Pathology, U. S. Department of Agriculture.

the tree just below the surface of the ground, causing butt rot; and one enters through branch stubs, knot holes, or other openings through the living sapwood in the upper portion of the tree, producing the true redheart. This disease is probably the most usual and is caused by *Trametes pini*. It travels downward and sometimes reaches to the base of the tree, leaving the wood firm rather than powdery, of a rich or dark reddish color, and permeated by oval or lens-shaped pockets of a light-gray color. The well-known dark-colored "punks," or fruiting bodies, are almost invariably from this species, since the other two common fungi have annual fruiting bodies.

The *Polyporus schweinitzii* leaves the wood in characteristic brown-colored cubical blocks. The fruiting bodies are hairy on top, brown inside, and weather brown. They are short-lived and are seldom seen. The sporophore or "punk" of *Polyporus sulphureus* is yellow on the outside changing to white, and its contents is white. Its work may be known by characteristic white bands of mycelium, which radiate outward from the center of the tree, filling the cracks in the rotted wood with felt-like masses of fungous tissue.

In cutting stands up to 70 years old heart rot is found infrequently. The liability to infection increases with the declining vitality of the tree. In one representative even-aged forest stand, 60 to 65, years in central Arkansas, only 2.2 per cent of the logs showed injury by fungi. In four large even-aged groups of shortleaf pine, 170 years old, the diseased logs ranged from 20 to 27 per cent of the total number of logs utilized, or 17.4 per cent of all logs, including sound logs left in the tops, which are merchantable or will be soon. A record of the infected logs in virgin timber at a large sawmill in Pike County, Ark., for March, April, and May, 1912, showed 25,689 sound logs and 4,430, or 14.7 per cent of the total logs, unsound. The log scale was slightly more than 3⅓ million board feet. The average run of infected timber for central Arkansas is further indicated in Table 14.

TABLE 14.—*Amount of "redheart" infection in average forest run shortleaf pine, mostly 60 to 180 years old.*[1]

Date.	Total cut for month.	Redheart defect.	Percentage sound.	Percentage infected with redheart.
1912.	*Board feet.*	*Board feet.*		
June	1,907,461	232,685	88	12
July	1,741,235	203,769	88	12
August	1,597,014	259,639	84	16
September	1,862,025	155,513	92	08
October	1,185,132	143,307	88	12
November	1,087,018	119,339	89	11
December	1,008,959	87,027	91	09
1913.				
January	1,147,115	128,436	89	11
February	754,610	85,723	89	11
March	1,048,638	118,692	89	11
April	994,102	100,662	90	10
May	1,178,236	110,996	91	09
Total	15,511,545	1,745,789	89	11

[1] Includes both butt rot and true redheart. Tally for a large representative mill in Clark County, Ark.

In a year's forest cut of shortleaf timber the average loss by redheart was 11 per cent of the total cut. The trees were mostly between 60 and 180 years old, some being 200 years old.

The wounds through which the spores enter the tree are caused partly by wind and sleet storms breaking the branches, but more largely by fires, which kill a portion of the sapwood, thus exposing the heartwood to infection. Thrifty young trees are to a considerable extent protected from infection by the resinous exudations which quickly form over wounds. The "punk," or fruiting bodies, of the fungus frequently occur near the place of attack, and, for butt-rotting fungi, are usually located on the lower half of the trunk. The damage can be very largely controlled by eliminating the chief cause—fire. In the more intensive management of small tracts of timber, so far as possible the diseased trees should be felled. The removal from the tree of the sporophores, or "punks," is of slight temporary benefit only, since it stimulates the formation of new fruiting bodies at other places on the tree.

Sap stain, or "bluing" of the sapwood, generally agreed among investigators to be the direct result of a fungus, is the most perceptible and the most controllable form of fungous injury. The reduction in value of stained lumber results in enormous annual loss. Since moisture and heat are favorable to the development and spread of the organism, the South suffers badly, but the presence of resin in the pines aids in checking the attack. In addition to the usual method of rapid drying of the wood, experiments have been conducted in chemically treating the wood of shortleaf pine with a view of preventing attack from sap-stained fungi.

WIND AND LIGHTNING.

Over the greater part of its range, shortleaf is only slightly susceptible to wind damage. This is due to its deep root system and its situation chiefly on the lighter, better-drained soils. Other aids to protection against wind are its short leaves, slender branches, and narrow crown. On the other hand, shortleaf is the only pine that extends well into the tornado[1] region of the Middle Western States. Here considerable damage is done every year, particularly in the Ozark uplands of Missouri, Arkansas, and Oklahoma. Strips of wind-thrown forest are present in all stages of recovery. After the decay of the thrown timber these are easily recognized by the even-aged stand, usually of pure pine, in the central area, with the two-storied and high-forest condition in increasing degree toward the margin of the cyclone strip. On account of its quick response to light and the small size and abundance of its seed, the occurrence of tornadoes has extensively aided the formation of pure, even-aged

[1] Known commonly as "cyclone."

stands of pine. Near Womble, on the Arkansas National Forest, is such a fully stocked, even-aged stand on a strip averaging approximately one-half mile in width by 14 miles in length. The tornado occurred on May 8, 1882, and a large amount of the young stand dates from the same spring, showing the coincidence of a heavy seed crop the previous fall and favorable conditions for germination.

Damage from ice storms is increased by the effect of wind upon the heavily laden trees. Ice or sleet storms cause serious injury at varying intervals of 6 to 12 years. An ice storm in December, 1898, in southwestern Arkansas uprooted and broke down so many trees that it completely blocked road traffic over all of the timbered roads for nearly one week. The damage from snow press is relatively small.

Lightning kills trees occasionally and injures very many. The secondary injury from winds and lightning is possibly even greater than the direct effect, since injurious insects and fungi find their chief avenue of attack in freshly opened wounds in the bark and cambium, or living layer, of the tree.

YIELD.

FACTORS INFLUENCING YIELD.

The growth of a stand as a whole determines its productiveness or yield. First, regions favorable to the greatest volume production in the individual tree likewise produce the largest crops or highest yields per acre of timber. The yield of well-stocked stands of 65-year-old shortleaf in central North Carolina is much greater than that of stands of similar age and density in New Jersey, and in the Arkansas-Louisiana region not less than 20 per cent greater than in North Carolina.[1] Second, the number of trees per acre affects directly the size and volume production of the individual tree and of the stand, and therefore the quality of the yield. Overstocked as well as understocked stands decline rapidly in saw-timber production as the number of trees departs in either direction from the normal or best condition of stocking. The decline in total cubic volume is not so great, especially in fully stocked stands. What the conditions are in any region can be accurately determined by measuring stands similar in all points except the degree of stocking. One nearly always finds wide differences occurring in respect to the number of trees per acre and the corresponding yields, both within adjacent stands and in portions of the same stand. Third, the yield varies with the age of the stand. The yield of a stand rises with age to a point of maximum production, after which there is a decline due to the progress of natural thinning by the loss of trees through declining vigor and

[1] This difference is undoubtedly due to regional differences in the supply of atmospheric and soil moisture, temperature, and the physical texture and composition of the soil.

attacks of natural enemies of various sorts. In good situations in Arkansas, for instance, well-stocked 160-year-old stands of shortleaf have average yields of about 45,000 board feet, or approximately the same as 58-year-old stands on similar situations. The point of highest average annual production of natural unthinned stands is probably between 90 and 100 years in Arkansas and some 10 years earlier in the central Piedmont region bordering the Atlantic coastal plain.

TABLE 15.—*Relation between tree density and yield per acre for 30-year-old shortleaf pine.*

[Yield from trees 8 inches and over in diameter. Based on 7 sample areas in Arkansas in stands of similar soil, protected against fires, and ranging from 210 to 780 trees per acre in quality I site.]

Trees per acre.		Yield (saw timber).		Average diameter.
Total.	8 inches and over in diameter.	Scribner rule.	Doyle rule.	
		Feet b. m.	*Feet b. m.*	*Inches.*
150	130	11,250	6,600	11.5
200	175	13,500	8,450	10.9
250	215	16,000	9,700	10.4
300	260	18,100	10,600	9.8
350	290	19,400	10,800	9.4
400	290	19,100	10,200	8.9
450	260	17,500	9,000	8.5
500	255	15,350	7,900	8.1
550	235	13,200	6.800	7.7
600	215	11,250	5,800	7.3
650	195	9,250	4,450	7.0
700	180	7,500	3,200	6.6
750	160	5,900	2,000	6.3
800	140	4,250	800	6.0

YIELD IN PURE STANDS.

Old growth or virgin stands in regions of good development show yields averaging 10 to 30 thousand board feet per acre over considerable areas. Most of such tracts are at the present time found only in the more inaccessible regions in the upper portions of the middle Atlantic coastal States and in the Louisiana-Arkansas district. Much larger amounts occur in mixed stands with hardwoods.

Fully stocked tracts of shortleaf pine in natural stands are scattered and rarely occur in areas of considerable size. Irregular stocking at the outset, fire, and other causes produce many open spaces where trees are needed to complete the stand. In other places the stand has from the start maintained too many trees per acre to give the best results in quality or quantity of product. The average yields of natural stands, therefore, vary widely and have little significance in considering the habits and possibilities of the tree when growing in full stands. The best basis for considering the yield of forest trees like shortleaf which occur in pure stands is the yield of fully stocked stands or portions of stands growing under known conditions of situation. Such information, when classified by age and site quality for normally stocked stands, is known as a normal yield

table. Tables 16, 17, and 18 have been thus prepared by measuring portions of well-stocked second-growth or old-field stands of known age and quality of natural environment, particularly character of soil and moisture supply. For example, the average yield of 50-year-old stands on the best class of sites in North Carolina (Table 16) is about 23,700 board feet, on medium or average sites 17,000, and on the poorest sites about 10,300 board feet. Table 18 shows yields in the Arkansas region at 50 years of 37,200, 23,750, and 12,200 board feet, respectively, on the three qualities of site. The original figures for North Carolina were secured from 80 selected sample tracts with an area of 21.6 acres, which may be considered fairly representative. The data for Table 18 are insufficient in amount, hence the table is tentative and has been included for the purpose of comparison and correction when more measurements become available.

TABLE 16.—*Yield of well-stocked second-growth shortleaf pine in North Carolina.*[1]

[Based on 80 sample plots in well-stocked stands; total area, 21.6 acres. Saw timber scaled to 6 inches in top diameter; stump height, 1 to 1.5 feet. Volume of stem is from 1-foot stump to 6-inch top diameter, including bark. All trees 6 inches and over diameter breast high were scaled.]

QUALITY I.

Age (years).	Trees per acre.	Average diameter breast high.	Average height.	Total basal area.	Yield per acre.		
					Saw timber.		Solid contents.
					Scribner rule.	Doyle rule.	
		Inches.	*Feet.*	*Sq. ft.*	*Bd. ft.*	*Bd. ft.*	*Cu. ft.*
10	2,940	2.8	22	104	400	....	1,050
15	1,760	4.4	32	135	3,000	300	1,560
20	1,000	5.8	40	158	5,700	2,000	2,120
25	675	6.9	46	175	8,400	3,600	2,730
30	510	7.9	51	188	11,200	5,300	3,350
35	410	8.8	55	198	14,000	7,100	3,950
40	340	9.6	59	205	17,100	8,900	4,570
45	280	10.4	63	211	20,300	10,900	5,200
50	235	11.2	66	215	23,700	12,800	5,840
55	200	11.9	69	218	27,000	14,500	6,450
60	165	12.7	72	220	30,100	16,200	7,020
65	140	13.4	74	222	33,200	17,700	7,570
70	120	14.1	77	224	36,100	19,300	8,100
75	100	14.7	79	226	38,800	20,800	8,600
80	90	15.3	81	227	41,500	22,400	9,110

QUALITY II.

Age (years).	Trees per acre.	Average diameter breast high.	Average height.	Total basal area.	Scribner rule.	Doyle rule.	Solid contents.
10	3,725	2.2	18	82	....	....	660
15	2,450	3.4	26	108	1,100	....	1,000
20	1,635	4.6	33	129	3,200	300	1,380
25	1,095	5.6	38	145	5,200	1,700	1,840
30	765	6.5	43	156	7,300	3,200	2,330
35	600	7.3	47	165	9,400	4,700	2,820
40	500	8.0	50	172	11,700	6,300	3,320
45	420	8.7	54	176	14,300	7,900	3,830
50	355	9.4	57	179	17,000	9,500	4,360
55	310	10.0	59	182	19,700	11,000	4,880
60	270	10.6	62	183	22,400	12,500	5,360
65	230	11.3	64	185	25,200	13,900	5,830
70	205	11.8	66	186	27,800	15,300	6,280
75	180	12.4	69	187	30,400	16,700	6,730
80	155	13.0	71	188	32,900	18,100	7,160

[1] Counties in North Carolina are: Alexander, Burke, Cabarrus, Catawba, Cleveland, Davie, Gaston, Lincoln, McDowell, Rowan, Rutherford, Surry, Wilkes, and Yadkin.

TABLE 16.—*Yield of well-stocked second-growth shortleaf pine in North Carolina.*—Con.

QUALITY III.

Age (years).	Trees per acre.	Average diameter breast high.	Average height.	Total basal area.	Yield per acre. Saw timber. Scribner rule.	Yield per acre. Saw timber. Doyle rule.	Yield per acre. Solid contents.
		Inches.	*Feet.*	*Sq. ft.*	*Bd. ft.*	*Bd. ft.*	*Cu. ft.*
10	....	1.6	14	60	....	....	290
15	3,270	2.5	21	82	....	....	450
20	2,450	3.4	26	100	700	....	650
25	1,880	4.2	31	114	2,100	....	930
30	1,405	5.0	35	125	3,400	1,100	1,290
35	1,045	5.7	39	133	4,800	2,300	1,670
40	795	6.4	42	138	6,500	3,600	2,070
45	655	7.0	45	142	8,300	4,900	2,470
50	550	7.6	47	144	10,300	6,200	2,880
55	475	8.2	50	145	12,400	7,500	3,300
60	420	8.7	52	146	14,700	8,800	3,700
65	370	9.2	54	147	17,100	10,100	4,100
70	330	9.7	56	148	19,600	11,400	4,490
75	295	10.2	58	149	22,000	12,600	4,860
80	270	10.6	60	149	24,200	13,900	5,230

TABLE 17.—*Yearly increment of second-growth shortleaf pine in North Carolina.*[1]

[Based on 80 sample plots in well-stocked stands; total area, 21.6 acres. Saw timber scaled to 6 inches in top diameter. Stump height, 1 to 1.5 feet. Volume of stem is from 1-foot stump to 6-inch top diameter, including bark. All trees 6 inches and over diameter breast high were scaled.]

PERIODIC ANNUAL INCREMENT.

Age (years).	Scribner rule. Quality I.	Scribner rule. Quality II.	Scribner rule. Quality III.	Doyle rule. Quality I.	Doyle rule. Quality II.	Doyle rule. Quality III.	Solid contents. Quality I.	Solid contents. Quality II.	Solid contents. Quality III.
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
20	500	370	....	300	....	....	112	82	50
25	530	400	240	320	280	....	117	88	59
30	560	430	275	340	295	....	121	93	66
35	590	460	310	360	310	240	124	98	72
40	620	485	340	380	315	250	126	101	76
45	650	505	370	**400**	**320**	255	127	104	80
50	**680**	525	400	380	315	255	**128**	**106**	82
55	655	540	425	365	310	260	123	104	**84**
60	625	550	455	350	300	**260**	117	101	83
65	605	**560**	475	330	290	260	112	97	81
70	580	545	**500**	315	280	260	106	92	78
75	560	520	475	300	275	255	100	87	75
80	540	490	445	285	265	250	94	82	71

MEAN ANNUAL INCREMENT.

Age (years).	Scribner rule. Quality I.	Scribner rule. Quality II.	Scribner rule. Quality III.	Doyle rule. Quality I.	Doyle rule. Quality II.	Doyle rule. Quality III.	Solid contents. Quality I.	Solid contents. Quality II.	Solid contents. Quality III.
20	285	175	50	100	15	....	107	69	32
25	335	205	80	140	65	....	109	74	38
30	370	240	110	175	105	35	111	78	43
35	405	270	135	205	135	65	113	81	48
40	430	295	160	225	160	90	115	83	52
45	450	320	185	245	175	110	116	85	55
50	470	340	205	255	190	125	117	87	58
55	490	360	225	265	200	135	117	88	60
60	500	375	245	270	210	145	117	89	62
65	510	385	260	275	215	155	116	90	63
70	515	395	275	275	220	165	116	90	64
75	520	405	295	280	225	170	115	90	65
80	520	410	310	280	225	175	114	90	65

[1] Counties in North Carolina are: Alexander, Burke, Cabarrus, Catawba, Cleveland, Davie, Gaston, Lincoln, McDowell, Rowan, Rutherford, Surry, Wilkes, and Yadkin.

TABLE 18.—*Yield of second-growth shortleaf pine in Arkansas.*

[Based on 38 fully stocked sample plots; area, 5.8 acres. All trees 6 inches and over in diameter breast high were scaled. Top diameter, 5.5 inches; stump height, 1 foot; number of trees per acre, see page 17.]

Age (years).	Average height of tree.	Average diameter 6 inches and over.	Total basal area (breast high) per acre.	Yield per acre. Saw timber. Scribner rule.	Yield per acre. Saw timber. Doyle rule.	Yield per acre. Total volume.
	Feet.	*Inches.*	*Sq. ft.*	*Bd. ft.*	*Bd. ft.*	*Cu. ft.*
QUALITY I.						
20	43	7.5	166	8,000	....	2,500
25	50	8.6	182	12,700	4,200	3,630
30	55	9.6	195	17,500	6,600	4,900
35	60	10.6	205	22,400	9,700	6,060
40	65	11.4	213	27,500	13,400	7,010
45	69	12.2	219	32,500	17,600	7,730
50	73	13.0	225	37,400	21,800	8,320
55	76	13.6	230	42,200	25,600	8,850
60	79	14.2	234	46,850	29,000	9,320
65	81	14.8	237	51,350	32,100	9,760
70	84	15.3	240	55,750	35,000	10,160
75	86	15.8	242	....	37,800	10,520
80	88	16.2	243	....	40,500	10,850
QUALITY II.						
20	35	6.6	125	4,350	....	1,740
25	41	7.5	139	7,450	2,700	2,520
30	46	8.3	150	10,600	4,500	3,390
35	51	9.1	159	13,800	6,800	4,220
40	55	9.9	167	17,000	9,500	4,930
45	58	10.7	173	20,200	12,400	5,520
50	61	11.3	178	23,450	15,400	6,050
55	64	12.0	183	26,850	18,200	6,520
60	67	12.5	186	30,600	20,600	6,980
65	69	13.1	189	34,050	23,000	7,410
70	72	13.6	191	37,500	25,200	7,800
75	74	14.1	193	40,850	27,400	8,160
80	76	14.5	194	44,000	29,500	8,500
QUALITY III.						
20	....	....	....	....	....	....
25	33	6.3	95	2,600	1,200	1,390
30	37	7.0	105	4,300	2,500	1,870
35	41	7.7	113	6,000	3,900	2,360
40	44	8.4	120	7,900	5,500	2,850
45	47	9.1	126	10,000	7,200	3,310
50	50	9.7	131	12,200	9,000	3,760
55	53	10.3	135	14,600	10,600	4,210
60	55	10.8	138	17,100	12,300	4,650
65	57	11.4	140	19,600	13,900	5,070
70	59	11.9	142	22,000	15,400	5,450
75	61	12.4	143	24,600	16,900	5,810
80	63	12.9	143	27,100	18,400	6,150

SCOTCH AND SHORTLEAF PINES.

In a number of silvical features Scotch pine (*Pinus sylvestris*) and shortleaf pine appear to be quite similar.

Both trees belong to the two-leaved group of pines[1] and form close stands made up of tall stems, free from branches for two-thirds of their length and terminating in short compact crowns. Both are vigorous and hardy growers and not subject to any markedly serious parasitic fungous disease. While both species are adapted to the drier type of soil occurring on the uplands, they differ in belonging characteristically to different zones of climate. Scotch pine does not require nearly so much heat during the summer and will endure much lower temperatures than shortleaf in winter. The seeds of both appear practically the same in size and general vigor, and both species are readily grown in the nursery. Shortleaf, however, regenerates itself by sprouting from the stump, inherently possesses a much straighter stem, has smaller-sized branches, and cleans itself more quickly in stands. Fully stocked stands of Scotch pine at any specified age contain a greater number of trees, although of smaller size than shortleaf pine indicating a somewhat greater degree of tolerance.

All measurements of yield show considerably larger returns from shortleaf than from Scotch pine. The maximum average annual growth per acre of shortleaf pine on the best quality sites in North Carolina is 117 cubic feet at the age of 55 years; that of Scotch pine in Germany, about 90 cubic feet at 55 years. These maximum yields range downward on the poorest quality sites to 65 cubic feet at 80 years for shortleaf pine and about 40 cubic feet for Scotch pine at 65 years. Weise's table for Scotch pine is based upon 351 sample tracts located in 5 German States, while the shortleaf-pine table shows the results of only 80 sample tracts located in 14 counties in North Carolina. Table 19 shows several points of likeness and unlikeness in these two pines. The shortleaf data are not so representative of the species as that for Scotch pine. The German plots were all normal stands, last thinned just prior to the measurement, while the North Carolina shortleaf plots were average well-stocked natural untreated stands in old fields, thinned somewhat by the action of fires. Under these unlike conditions the results can not be fairly comparable, but may be taken as an indication of the character and possibilities of the two pines.

In respect to height, shortleaf pine leads under all conditions of age and situation, but the difference is most marked during about the first 30 to 40 years, and on the poorer sites at all ages up to 80 years.

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[1] Shortleaf varies to three leaves in the bundle on the vigorous growing parts of the crown.

TABLE 19.—*Yield of shortleaf pine in North Carolina, compared with yield of Scotch pine in Germany.*[1]

Characters compared.	Scotch pine.			Shortleaf pine.		
	Quality I.	Quality II.	Quality III.	Quality I.	Quality II.	Quality III.
Trees per acre:						
Trees 30 years old	1,543	2,536	....	510	765	1,405
Trees 50 years old	590	758	1,200	235	355	550
Trees 80 years old	206	317	585	90	155	270
Diameter, breast high (inches):						
Trees 30 years old	4.0	2.8	....	7.9	6.5	5.0
Trees 50 years old	7.3	5.8	4.2	11.2	9.4	7.6
Trees 80 years old	11.5	9.4	6.7	15.3	13.0	10.6
Basal area, breast high, total per acre (square feet):						
Trees 30 years old	130	104	67	188	156	125
Trees 50 years old	167	135	108	215	179	144
Trees 80 years old	184	151	132	227	188	149
Height, average (feet):						
Trees 30 years old	34	26	21	51	43	35
Trees 50 years old	68	43	34	66	57	47
Trees 80 years old	79	63	48	81	71	60
Yield, total per acre (cubic feet):[2]						
Trees 30 years old	1,690	830	400	3,350	2,350	1,300
Trees 50 years old	4,500	2,700	1,730	5,850	4,350	2,900
Trees 80 years old	6,570	4,260	2,930	9,100	7,150	5,250
Periodic annual increment (cubic feet):						
Trees 30 years old	92	98	49	121	93	66
Trees 50 years old	103	68	61	128	106	82
Trees 80 years old	53	44	24	94	82	71
Mean annual increment (cubic feet):						
Trees 30 years old	57	28	14	111	78	43
Trees 50 years old	90	54	35	117	87	58
Trees 80 years old	82	53	37	114	90	65

[1] Figures from Weise's yield tables for Scotch pine, Quality I and II averaged to make I; III taken as II; and IV and V averaged to make Quality III.

[2] Yield of Scotch pine taken for all wood down to 3 inches in diameter; of shortleaf pine taken only for trees up to 6 inches diameter breast high, and to 6 inches in tops.

The superiority of shortleaf over Scotch pine in size of trees and total yield is striking. Scotch-pine stands contain from two to three times as many trees per acre as the shortleaf stands, and the trees have correspondingly smaller average diameters. A comparison of the total yield of the two species is interesting. At the age of 30 years shortleaf shows about two or three times the yield of the Scotch pine for the better and poorer sites, respectively. At 50 years on first quality situations, the two species approach the closest in yield, yet the yield of shortleaf is just 30 per cent greater than that of Scotch pine. The shortleaf yield is again about 56 per cent greater at the age of 80 years. Similar yield tables for Scotch pine by Dr. Schwappach show usually from 15 to 20 per cent less yield than Weise's tables.

YIELD IN MIXED STANDS.

In mixed pine and hardwood stands the yield of shortleaf varies widely. In the lower mountains of northern Georgia recent timber estimates made by the Appalachian surveys show an average yield of 1,000 to 3,000 board feet per acre; but on the warmer slopes in the same region, pure virgin pine stands of mixed ages covering

several hundred acres yield from 12,000 to 20,000 board feet per acre.

Hundreds of square miles of the better shortleaf forests mixed with oak and hickory over central and western Arkansas and adjacent parts of Oklahoma and Louisiana will cut an average of about 5,000 board feet of shortleaf. The character of the forests in the more mountainous parts of Arkansas, where shortleaf is confined chiefly to the flats and warm south slopes, is seen in Table 2, showing the composition of the forest cover in the Arkansas and Ozark National Forests. In the higher hilly region of the Arkansas National Forest, cutting to an approximate diameter limit of 14 inches breast high, or about 15 inches on a 1-foot stump, the pine in the mixed type commonly yields about 2,000 board feet [1] of merchantable timber per acre, leaving about 1,000 feet for seed trees and second cut.

The average run in private cutting, down to a 12-inch stump diameter limit, is 10 logs per thousand board feet. In a representative sale on the Arkansas National Forest, cutting to a 14-inch diameter limit at breast height, the logs averaged 135 feet each, or 8 logs per thousand. The bulk of the timber cut ranged from 60 to 180 years old. The oldest good-sized groups or small stands observed over a wide district in central Arkansas were 170 to 180 years, and a large number of them were found throughout the whole region. The yields of these groups or small-sized stands ranged mostly between 25,000 and 35,000 board feet per acre, and the maximum acre measured was 62,000 board feet. In Montgomery County, Ark., a company recently cut 2,500 feet per acre (Doyle log scale), or an actual mill cut of nearly 4,000 feet of lumber per acre, from a private tract of 4,000 acres in the high hilly country within the Arkansas National Forest. The best cut of this company was 910,560 (Doyle scale) on 160 acres, or an actual mill cut of somewhat better than 1,500,000 feet, an average of approximately 9,500 feet per acre.

[1] Based upon growth and reproduction plots on the Arkansas National Forest in average cut-over tracts, 1912.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 245

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

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FURTHER EXPERIMENTS IN THE DESTRUCTION OF FLY LARVÆ IN HORSE MANURE.

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INTRODUCTION.

The results reported in this bulletin are a continuation of the investigation dealt with in Bulletin No. 118, United States Department of Agriculture, inaugurated for the purpose of finding a substance that would destroy the larvæ of the house fly in their principal breeding place, namely, horse manure, without injuring the bacteria or reducing in any way the fertilizing value of the manure (Cook, Hutchison, and Scales, 1914). The work was conducted in cooperation by the Bureaus of Entomology, Chemistry, and Plant Industry at Arlington, Va., and New Orleans, La. The bacteriological work at New Orleans was done by Dr. William Seemann, dean of the Tulane School of Tropical Medicine, and thanks are due him for his cooperation. The entomological work at New Orleans was done by Mr. E. R. Barber, scientific assistant, Bureau of Entomology.

In Bulletin No. 118 it was suggested that manure be treated with borax immediately on removal from the barn in order to destroy the eggs and maggots of the house fly, and that borax be applied at the rate of 0.62 pound per 8 bushels, or 10 cubic feet, of manure. As large quantities of manure are used by truck growers, it was thought advisable to include in that bulletin a warning as to the possible injurious action of large applications of borax-treated manure on plants. For the same reason it seemed desirable to find some volatile or other organic substance which would be effective as a larvicide, but without possible toxic action on vegetation. Largely with this object in view, the investigation was continued during 1914. The larvicidal value of some inorganic substances was also tested.

Borax may be used with advantage for the treatment of outhouses, public dumps, and refuse piles of all kinds, cracks and crevices, floors of stables, and any accumulation of organic material which offers a

favorable place for the deposition of eggs. A treatment two or three times a week ought to suffice for all these cases except where large quantities of organic material are added, when the borax application should be made immediately, using the same quantity as in the treatment of horse manure. The best results are always obtained when the borax is applied in solution daily, as it is effective against the eggs and the maggots during their feeding period. (Table V, series 52, G and H.) Borax probably has no effect on the pupæ or adult flies.

GENERAL PLAN OF EXPERIMENTAL WORK.

CAGE EXPERIMENTS.

The plan of the work was the same as that outlined in Bulletin No. 118, and in addition a few experiments were carried out in concrete pits. New cages were constructed for the experiments at Arlington. In order to prevent the escape of larvæ by migration, the galvanized-iron pans in the cages in which the manure was placed were made 2 feet deep, and the small openings in the bottom of the pans through which the water drained off were covered with fine wire gauze. The legs were made 8 inches high to facilitate the removal of any larvæ which might get into the drip pans.

The manure was sprinkled in three layers by putting 2 bushels of manure in the cage and applying 2½ gallons of the solution. This was repeated in the second layer of 2 bushels. Finally the remaining 4 bushels were added and the last 5 gallons of the solution applied. When a chemical was applied in dry condition it was scattered over the surface of the manure, which was also treated in three layers, and 10 gallons of water were afterwards added. The manure in the control cages was sprinkled with water equal to the volume of the solutions used. The flies which were caught in the traps attached to the top of the cages were chloroformed and counted, and at the end of each experiment a comparison of the total number was made, and from these counts an index of the effectiveness of the chemical was obtained. Only fresh manure was used in the experiments, and every effort was made to provide for an even distribution of fly eggs and larvæ. That it was impossible to secure an equal infestation in all cages is evident from a comparison of the fly counts from the control cages.

OPEN-PILE EXPERIMENTS.

A few open-pile experiments were carried out at Arlington on the same plan as during the previous year. The most important open-pile experiments were conducted at New Orleans during November and December, 1914. In most of the New Orleans open-pile experiments 4 bushels of manure were sprinkled with 5 gallons of solution daily, and this was repeated four times, making a total pile of 16 bushels treated with 20 gallons of solution. The total number of

pupæ in each pile was counted about eight days after the last treatment. A sample of 200 pupæ from each pile was kept in the laboratory, and the percentage of emergence determined. From these data the apparent larvicidal effect was calculated. For some of the New Orleans experiments, cages (Pl. I, fig. 1, p. 16) were constructed to cover the piles, and instead of counting the number of pupæ the flies were allowed to emerge and were caught in traps attached to the tops of the cages. Temperatures and samples for analysis were taken through the armholes in the sides of the cages. Soil was banked against the base of the cages to prevent the escape of maggots and flies.

Chemical and bacteriological analyses were made of samples of manure from most of the cage and open-pile experiments.

SAMPLING FOR CHEMICAL AND BACTERIOLOGICAL ANALYSES.

It is very evident that a manure pile with the unequal distribution and great variation of its physical and chemical constituents will necessarily be exceedingly difficult to sample, especially to secure from it a few hundred grams which will be thoroughly representative. An attempt was made to secure representative samples by taking equal portions of manure from three different parts of the pile, spreading them on a clean sheet of paper, and finely dividing and thoroughly mixing them. When the material appeared quite uniform the sample was quartered. One quarter was then cut into half-centimeter lengths with clean shears. The straw or shavings were cut with the other material. When this operation was completed the sample was again thoroughly mixed. For chemical analysis the material was twice passed through a grinder. Both bacteriological and chemical examinations were made on the same sample. As the bacterial content of manure is very high, no attempt was made to work under absolutely sterile conditions, because the contamination arising from ordinary handling of the material was of no importance when compared with the great number of organisms present. However, precautions were taken to prevent excessive contamination by using clean paper, shears, etc., for each sample.

BACTERIOLOGICAL EXAMINATION.

Two 10-gram samples of the manure, prepared as just described, were taken for each bacteriological determination. One of the 10-gram samples was dried at 100° C. for one hour to determine the percentage of solids. The other sample was brushed into a 2-liter flask containing 1 liter of sterile water. The flask was then vigorously shaken for five minutes and again, after a five minute interval, for three minutes. A 1-c. c. sample was then withdrawn and run into 100 c. c. of sterile water. Five dilutions were prepared, ranging from 1 part in 10,000 to 1 part in 100,000,000. A duplicate series of Petri dishes was then prepared from these dilutions and standard beef agar.

After five days' incubation at 28 to 30° C. the plates were counted. The average counts of the duplicate plates were taken and converted into equivalents for 1 gram of dry manure by the use of the figures obtained from the duplicate 10-gram samples that had been dried at 100° C. The results obtained by plating on the standard beef agar are comparative and serve to show the germicidal action of the chemicals on the majority of the bacteria present in the manure. Dr. Seemann, in the work at New Orleans, used a medium prepared from manure water, but the counts were practically the same as those on beef agar.

CHEMICAL EXAMINATION.

The manure samples were analyzed for solids, ash, ammonia, and nitrogen, using the methods of the Association of Agricultural Chemists (Wiley, 1908). The total nitrogen determinations were made by the Nitrogen Laboratory of the Bureau of Chemistry. The results obtained by the magnesium-oxid distillation method for ammonia, which are not reported in the table, although much higher, showed the same general tendencies as the figures obtained on the water extracts.

Water extracts were prepared from each sample by taking 25 grams of the finely divided manure and adding 500 c. c. of distilled water, allowing them to stand for one hour, with occasional shaking. The solutions were filtered, and the following determinations were made: Water-soluble nitrogen, ammonia, nitrites, nitrates, and reaction.

Ammonia was extracted by the Folin and Macallum (1912) aeration method and nesslerized. Nitrites were determined with the sulphanilic acid reagent, and nitrates by the reduction method with aluminum foil (American Public Health Association, Laboratory Section, 1912). Nitrites and nitrates were not usually found in the samples examined, because the manure had not stood sufficiently long. The reaction was determined by taking 20 c. c. of the water extract, diluting with 200 c. c. of carbon-dioxid free water, and titrating with twentieth normal acid, using alizarin red as indicator.

GENERAL ACCOUNT OF SUBSTANCES USED.

Representatives of two groups of substances were tested during the season's work, namely, (1) inorganic and (2) organic, including volatile and nonvolatile substances and some plant material. These substances are arranged in alphabetical order in the respective groups.

INORGANIC SUBSTANCES.

Of the inorganic substances, arsenical dip, chlorid of lime, Epsom salts, lime-sulphur, and sulphuric acid in three concentrations were used.

ARSENICAL DIP.

Arsenical dip, which is extensively used in the West and Southwest to kill ticks on cattle and sheep, was prepared according to the directions given in U. S. Department of Agriculture Farmers' Bulletin No. 603 (Chapin, 1914). This solution was used in three cage experiments, namely, full strength, and diluted 1 to 1 and 1 to 3 (Table I, Series 67, A, B, and C).

TABLE I.—*Destruction of fly larvæ in horse manure. Results with arsenical dip, para-dichlorobenzene, and pyridine; cage experiments at Arlington, Va., 1914.*

Series.		Treatment of 8 bushels of manure, using 10 gallons of liquid.	Flies emerged.	Apparent larvicidal effect.	Number of bacteria per 1 gram manure, calculated to dry weight.	Manure, total nitrogen.	Water extract.		
							Alkalinity, N/20 HCl per 100 c. c. (5 grams of manure).	Water-soluble nitrogen.	N as NH_3, Folin method.
			Number.	*Per cent of control average.*	*Millions.*	*Per cent.*	*C. c.*	*Per cent of total nitrogen.*	*Per cent of total nitrogen.*
67	A	Arsenical dip (strong)	67	87	1,648	0.421	10.50	33.63	3.5
	B	Arsenical dip (1–1)	57	89	1,944	.337	5.75	29.97	4.4
	C	Arsenical dip (1–3)	131	74	2,459	.547	6.50	33.82	3.7
70	A	Control (water only)	826		1,636	.625	6.40	27.84	
	B	do	382		1,043	.463	8.75	41.25	7.1
	C	do	275		843	.337	8.40	26.70	4.7
		Control average	494						
78	A	Pyridine, 1–100	37	63	634	.540	8.90	31.11	3.0
	B	Pyridine, 1–500	135	0	798	.540	8.65	31.11	3.7
81	A	Control (water only)	53		1,035	.611	9.90	26.68	1.9
	B	do	252		1,282	.639	11.15	36.93	2.4
	C	do	96						
		Control average	134						
104	A	Pyridine, 1–100	3	99+	209	.470	4.75	28.72	7.02
	B	do	2	99+	128	.449	4.50	33.85	2.45
106	A	Control (water only)	4,489		19.6	.572	4.25	25.00	2.10
	B	do	1,936		27.1	.561	4.65	26.02	1.41
		Control average	3,212						
79	A	Para-dichlorobenzene, ½ pound to 10 gallons water	10	93	905	.793	13.15	36.07	4.8
	B	do	70	50	502	.505	11.65	35.44	4.6
		(For control see 81, A, B, and C, above.)							
98	A	Para-dichlorobenzene, 1 pound to 10 gallons water	11	97					
	B	do	68	78					
99	A	Control (water only)	157		283	.898	11.40	25.61	2.34
	B	do	687		165	.653	10.75	24.19	4.13
	C	do	77		157	.533	8.15	27.39	2.44
		Control average	307						

The two stronger concentrations killed about 88 per cent of the maggots and the 1–3 solution about 75 per cent. The weaker strengths apparently exerted a slight stimulating action on the bacteria, and the full-strength dip showed no bactericidal action in this one test. The chemical data showed no marked differences except for the increased alkalinity where the dip was applied in full strength, and this, no doubt, was due to the sodium carbonate in the dip.

CHLORID OF LIME.

Chlorid of lime has been used extensively as a disinfectant and has been tested by Dr. Howard, who found that 1 pound applied to 8 quarts of manure killed practically all the larvæ, but one-fourth of a pound to 8 quarts was not sufficient (Howard, 1911). In our experiments with smaller amounts, namely three-fourths of a pound, $1\frac{1}{2}$ pounds, and 3 pounds to 8 bushels and the addition of 10 gallons of water, negative results were obtained. The well-known action of chlorid of lime in driving off the ammonia from manure, the probable toxic effect on bacteria, and the irritating action of the liberated chlorin, as well as the high cost of the substance in quantities sufficient to kill fly larvæ, precludes its use for this purpose.

EPSOM SALTS.

Epsom salts was applied in three cage experiments, using respectively 1, 2, and 4 pounds to 10 gallons of water. In no case was any larvicidal effect noticed. No chemical or bacteriological examinations were made.

LIME-SULPHUR.

Lime-sulphur was used again this year in dilutions of 1 to 10, 1 to 20, and 1 to 30. No larvicidal effect was seen, and since it failed to kill the maggots, no chemical or bacteriological analyses were made.

SULPHURIC ACID.

Sulphuric acid was used in 1, 2, and 3 per cent solutions. Two cage experiments with each concentration were carried out. Practically no larvicidal effects were shown in any of the experiments. Sufficient alkaline substances and organic material were present in the manure to combine with the acid in the 1 per cent and 2 per cent solutions, consequently no injurious action on the bacteria resulted. No counts were made where the 3 per cent solutions were applied. When the 3 per cent applications were made the alkaline reaction of the manure was markedly reduced and the percentage of ammonia, in terms of the total nitrogen, was increased from three to four times that of the control. The 1 per cent and 2 per cent solutions had no apparent action on the manure as determined by the chemical results.

ORGANIC SUBSTANCES.

As the application to the soil of manure containing inorganic substances is likely to produce harmful effects on plants, due to a slight excess of the toxic element in the soil, it seemed desirable to investigate the larvicidal action of various organic substances, both volatile and nonvolatile. The volatile substances would produce

a true partial sterilization, as has been shown by several investigators (cf. Russel and Buddin, 1913, and the recent article by the latter, Buddin, 1914), while the nonvolatile substances would be finally decomposed in the soil, and, therefore, have no permanent injurious effect. Organic substances, when added to the soil, may be attacked by various members of the soil flora, as bacteria and filamentous fungi, which either destroy the substances entirely or form compounds that may be utilized by other organisms which are of value in maintaining the fertility of the soil or may be utilized directly by the plants themselves.

ANILINE.

Aniline ($C_6H_5NH_2$), which is extensively used in the preparation of dyes, contains 15 per cent of nitrogen and costs about 60 cents per quart. This substance was tested in cage experiments at Arlington, Va., using dilutions of 1 to 50, 1 to 100, and 1 to 200.

TABLE II.—*Destruction of fly larvæ in horse manure. Results with aniline and nitrobenzene; cage experiments, Arlington, Va., 1914.*

Series.	Treatment of 8 bushels of manure, using 10 gallons of liquid.	Flies emerged.	Apparent larvicidal effect.	Number of bacteria per 1 gram manure, calculated to dry weight.	Manure, total nitrogen.	Water extract. Alkalinity, N/20 HCl per 100 c. c. (5 grams of manure).	Water extract. Water-soluble nitrogen.	Water extract. N as NH_3, Folin method.
		Number.	*Per cent of control average.*	*Millions.*	*Per cent.*	*C. c.*	*Per cent of total nitrogen.*	*Per cent of total nitrogen.*
94 A	Aniline, 1-50	4	98	264	0.526	8.25	41.63	7.98
94 B	Aniline, 1-100	11	97	392	.632	8.65	33.70	4.60
94 C	Aniline, 1-200	25	80	....	....	....	....	....
99 A	Control (water only)	157	....	283	.898	11.40	25.61	2.34
99 B	do	687	....	165	.653	10.75	24.19	4.13
99 C	do	77	....	157	.533	8.15	27.39	2.44
	Control average	307	....	....	....	....	....	....
100 A	Aniline, 1-200	17	99+	....	.618	4.15	25.08	1.40
100 B	do	28	99	....	.674	6.40	29.08	1.63
106 A	Control (water only)	4,489	....	19.6	.572	4.25	25.00	2.10
106 B	do	1,936	....	27.1	.561	4.65	26.02	1.41
	Control average	3,212	....	....	....	....	....	....
95 A	Nitrobenzene emulsion (3¼ pounds nitrobenzene and ½ pound fish-oil soap to 10 gallons water)	0	100	551	.547	9.75	34.92	9.14
95 B	do	1	99+	667	.526	8.10	40.50	7.41
95 C	Same as foregoing, diluted 1-3	115	63	....	....	....	....	....
99 A	Control (water only)	157	....	283	.898	11.40	25.61	2.34
99 B	do	687	....	165	.653	10.75	24.19	4.13
99 C	do	77	....	157	.533	8.15	27.39	2.44
	Control average	307	....	....	....	....	....	....
101 A	Nitrobenzene (1.67 pounds nitrobenzene and ⅓ pound fish-oil soap to 10 gallons water) undiluted	4	99+	....	.565	6.40	34.69	8.32
101 B	do	0	100	323	.449	5.40	34.96	9.13
101 C	Same as foregoing, diluted, 1-1	5	99+	....	....	....	....	....
106 A	Control (water only)	4,489	....	19.6	.572	4.25	25.00	2.10
106 B	do	1,936	....	27.1	.561	4.65	26.02	1.41
	Control average	3,212	....	....	....	....	....	....

The results given in Table II show a 97 and 98 per cent larvicidal action with the two stronger solutions, and in the case of the 1 to 200 dilution two cages showed a 99 per cent and one an 80 per cent larvicidal action. The 1 to 50 and 1 to 100 strengths showed an increased number of bacteria. The amount of water-soluble nitrogen and ammonia is noticeably increased in the manure treated with the strongest solution of aniline, with no apparent action on the bacteria. The increases of the water-soluble nitrogen and ammonia are probably due to nitrogen in the aniline added. Aniline, among other substances, was tried in some cage experiments at New Orleans, the results of which are given in Table III.

TABLE III.—*Destruction of fly larvæ in horse manure. Results with aniline, hellebore, and nitrobenzene; cage experiments at New Orleans, La., 1914.*

Series.		Treatment of 8 bushels of manure, using 10 gallons of liquid.	Flies emerged.	Larvæ in drip pans.
			Number.	*Number.*
107	A	Aniline, 1-200	3,738	2,380
	B	Aniline, 1-400	6,030	12,853
	C	do	5,070	9,856
108	A	Hellebore, ground, ½ pound to 10 gallons water	1,122	4,034
	B	do	820	4,567
	C	Hellebore, ground, ¼ pound to 10 gallons water	1,130	1,285
	D	do	874	1,930
109	A	Nitrobenzene, 1 pound, and ½ pound fish-oil soap to 10 gallons water	3,390	2,985
	B	do	1,692	3,647
	C	Nitrobenzene, ½ pound, and ¼ pound fish-oil soap to 10 gallons water	1,319	2,042
110	A	Control (water only)	1,085	560
	B	do	5,888	4,835
111	A	Aniline, 1-200	5,076	4,462
	B	Aniline, 1-400	12,667	8,296
	C	do	12,309	19,675
112	A	Hellebore, ground, ½ pound to 10 gallons water	11,803	10,794
	B	do	17,197	8,179
	C	Hellebore, ground, ¼ pound to 10 gallons water	20,067	9,315
	D	do	17,838	268
113	A	Nitrobenzene, 1 pound, and ½ pound fish-oil soap to 10 gallons water	2,395	10,132
	B	do	12	211
	C	Nitrobenzene, ½ pound, and ¼ pound fish-oil soap to 10 gallons water	9,678	11,165
114	A	Control (water only)	19,366	11,419
	B	do	18,838	10,726

The cages were the ones used the previous year and, as the figures show, large numbers of larvæ escaped. Apparently these results show a low larvicidal effect of aniline, but since the condition of the cages was unsatisfactory they should not be compared with the others, especially as they are the only ones, either in cages or open piles, where poor results with aniline were obtained.

Open-pile experiments at New Orleans, using a 1 to 200 dilution of aniline, killed 85 and 99 per cent of the fly maggots (Table IV, series 46, A and B); 1 to 400 dilutions in two piles gave 79 and 83 per cent larvicidal effect (Table V, series 41, C and D); and two piles treated with aniline, 1 to 500, showed an 84 per cent destruction of larvæ (Table V, series 49, A and B).

TABLE IV.—*Destruction of fly larvæ in horse manure. Results with aniline, hellebore, nitrobenzene, and pyridine; open-pile experiments, New Orleans, La., 1914.*

Series.		Treatment: 5 gallons liquid to 4 bushels manure; 4 treatments each, except series 44 and 45.	Pupæ found.	Emergence from sample of 200 pupæ.	Apparent larvicidal effect.	No. of bacteria per 1 gram manure calculated to dry weight.	Manure. Total nitrogen.	Water extract. Alkalinity, N/20 HCl per 100 c. c. (5 grams of manure).	Water extract. Water-soluble nitrogen.	Water extract. N as NH_3, Folin method.
			Number.	*Per cent.*	*Per cent of control.*	*Millions.*	*Per cent.*	*C. c.*	*Per cent of total nitrogen.*	*Per cent of total nitrogen.*
[1] 44	A	Hellebore, ground, ½ pound to 10 gallons water	43,335		58.9	56.5	0.358	5.00	25.14	13.99
	B	....do	40,046		62.0	24.2	.421	4.75	28.02	7.84
	C	Hellebore, ground, ¼ pound to 10 gallons water	58,021		44.9	382	.379	5.50	31.14	13.98
	D	....do	77,056		26.8	1,170	.379	4.65	29.55	12.40
	E	Control (water only)	105,196				.386	5.00	26.16	15.54
[1] 45	A	Hellebore, ground, ⅜ pound to 10 gallons water	[2] 49,311		30.9	590	.400	4.00	15.50	7.50
	B	....do	[2] 41,148		42.3	1,940	.400	3.90	15.50	5.50
	C	Hellebore, ground, ¼ pound to 10 gallons water	[2] 60,107		15.9	1,000	.477	4.25	13.00	5.45
	D	....do	[2] 36,201		49.3	440	.435	4.15	14.25	8.28
	E	Control (water only)	[2] 71,305			880	.379	4.25	13.18	6.07
46	A	Aniline, 1-200	28,439	32.5	85.0	2,990	.407	6.00	41.28	16.21
	B	....do	6,460	13.5	99.4	77	.470	6.25	35.74	17.02
	C	Hellebore, ground, ⅜ pound to 10 gallons water	34,104	80.0	55.8	2,140	.456	4.75	29.60	11.18
	D	....do	56,718	37.0	66.0	1,150	.435	5.25	33.56	15.63
	E	Control (water only)	61,714	93.0		625	.407	5.25	38.57	16.46
47	A	Nitrobenzene, ¼ pound, and fish-oil soap, ½ pound, to 10 gallons water	4,140	62.5	89.4	1,240	.428	7.00	27.57	16.35
	B	....do	7,927	56.5	81.5	533	.351	5.25	25.64	10.25
	C	Hellebore, ground, ⅜ pound to 10 gallons water	13,770	53.0	70.0	967	.337	4.25	23.44	10.98
	D	....do	12,640	57.5	70.2	1,780	.442	4.25	20.36	7.92
	E	Control (water only)	24,312	95.5		2,750	.365	5.65	27.94	12.06
48	A	Pyridine, 1-1,500	122,907	82.5	8.3	484	.512	5.50	32.81	12.30
	B	....do	76,705	75.5	47.6	750	.491	7.25	34.22	15.27
	C	Hellebore, ground, ½ pound to 10 gallons water	49,602	84.0	62.4	1,780	.547	6.40	31.08	15.54
	D	....do	77,431	80.0	44.0	1,330	.449	4.90	47.44	7.80
	E	Control (water only)	110,470	96.5			.505	7.25	35.64	13.86
53	A	Hellebore, powdered, ½ pound to 10 gallons of water (alkaloids, 0.24 per cent) [3]	787	65.0	89.7	97.2	.393	5.65	30.00	7.89
	B	Hellebore, powdered, ½ pound to 10 gallons of water (alkaloids, 0.26 per cent) [3]	811	68.0	88.9	60.2	.400	3.90	22.50	10.00
	C	Hellebore, powdered, ½ pound to 10 gallons of water (alkaloids, 0.41 per cent) [3]	596	72.0	91.3	64.0	.400	6.25	26.75	11.75
	D	....do.[3]	965	60.0	88.3	97.0	.379	5.25	28.23	13.98
	E	Control (water only)	4,942	91.0		80.7	.400	4.25	25.25	12.50

[1] In series 44 and 45 there were 3 applications made; the first at the rate of 10 gallons to 8 bushels, the second and third at the rate of 5 gallons to 4 bushels.

[2] Number of flies emerged.

[3] Nitrites and nitrates present.

TABLE V.—*Destruction of fly larvæ in horse manure. Results with aniline, hellebore, nitrobenzene, and pyridine; open-pile experiments, New Orleans, La., 1914.*

Series.		Treatment: 5 gallons liquid added to 4 bushels of manure; 4 applications.	Pupæ found.	Emergence from sample of 200 pupæ.	Apparent larvicidal effect.
			Number.	*Per cent*	*Per cent of control.*
41	A	Pyridine, 1-500	4,756		98.6
	B	.....do	1,948		99+
	C	Aniline, 1-400	70,642		79.4
	D	.....do	56,651		83.5
	E	Control	342,771		
42	A	Nitrobenzene, 1 pound and ½ pound fish-oil soap to 10 gallons water	96,053		75.0
	B	.....do	92,771		76.0
	C	Nitrobenzene, ½ pound and ¼ pound fish-oil soap to 10 gallons water	74,636		80.6
	D	.....do	92,954		76.0
	E	Control	385,403		
43	A	Hellebore, ground, ½ pound to 10 gallons water	564		99+
	B	.....do	772		99+
	C	Hellebore, ground, ¼ pound to 10 gallons water	13,265		95
	D	.....do	17,526		93.7
	E	Control	273,520		
49	A	Aniline, 1-500	1,707	67.0	84.2
	B	.....do	1,603	74.0	83.6
	C	Hellebore, powdered, ½ pound to 10 gallons water	502	52.0	96.4
	D	.....do	162	43.0	99.0
	E	Control (water only)	7,202		
50	A	Hellebore, powdered, ½ pound to 10 gallons water	398	49	97.8
	B	.....do	293	49	98.4
	C	.....do	449	40.5	98.0
	D	.....do	334	40.5	98.5
	E	Control (water only)	8,866	93	
51	A	Hellebore, powdered, ½ pound to 10 gallons water	7	23.8	99+
	B	.....do	14	23.8	99+
	C	Hellebore, powdered, ¼ pound to 10 gallons water	12,294	71.0	80.0
	D	.....do	24,233	71.0	60.0
	E	Control (water only)	43,733	95	
52	A	Nitrobenzene, ¼ pound and 1 pound fish-oil soap to 10 gallons water	3,036	63	93.4
	B	.....do	3,415	63	92.8
	C	Pyretheum, powdered, ½ pound to 10 gallons water	24,346	95.5	0
	D	.....do	31,379	95.5	0
	E	Hellebore, powdered, ⅜ pound to 10 gallons water	7,694	95	75.5
	F	.....do	5,725	95	81.8
	G	Borax, powdered, 1 pound to 10 gallons water	1,390	8.5	99+
	H	.....do	953	8.5	99+
	L	Control (water only)	29,831	98.5	

As only one duplicate set of open piles treated with aniline 1 to 200 was examined, the data are not sufficient on which to base any conclusion as to its effect on the bacteriological and chemical composition of the manure. Aniline in all open-pile experiments showed a high larvicidal efficiency even in the dilution of 1 to 500, but it should be handled with care because of its possible toxic effects.

BETA NAPHTHOL.

Beta naphthol was tried in three cage experiments, using solutions containing 0.1 pound, 0.33 pound, and 1 pound, respectively. Where the 1-pound application was made only 11 per cent of the maggots were killed, and in the other two cases the results were negative. No bacteriological or chemical examinations were made of the treated manure.

CRESYLIC ACID.

Cresylic acid, which is prepared from coal tar, was tried in dilutions of 1 to 20, 1 to 40, and 1 to 80 in cage experiments, but it was without action on the maggots. Bacteriological and chemical analyses were made of the manure treated with the 1 to 20 strength, and the bacteria were reduced 90 per cent. The alkalinity of the manure was reduced, and a slight increase in ammonia over that of the controls was found.

PARA-DICHLOROBENZENE.

Para-dichlorobenzene was employed in two sets of cage experiments, using one-half pound and 1 pound to 8 bushels of manure. The substance was ground and scattered over the manure, and water added. As shown (Table I, series 79, A and B, and 98, A and B), the apparent larvicidal effect varied greatly, the one-half pound strength indicating a 50 and 93 per cent action and the 1 pound indicating 78 and 97 per cent effectiveness. The bacterial counts and chemical analyses where the one-half pound applications were made showed only slight effects from this treatment. No analyses of the manure in the cages treated with the 1-pound applications were made. Para-dichlorobenzene was tried in one pit experiment. The pits were of concrete with inside measurements of 9 by 6 by 2 feet. Thirty-two bushels of manure were placed in the pits, and the manure in one pit was treated at the rate of 0.5 pound to 8 bushels. The other pit was untreated. From the former 403 flies emerged, and from the latter, 484. The larvicidal action was, therefore, apparently about 16 per cent. Duckett (1915) has found this substance to be an effective fumigant against various household insects and those affecting stored products.

FORMALDEHYDE.

Further experiments with formaldehyde were performed, using 1 to 6, 1 to 8, and 1 to 10 dilutions of the commercial 40 per cent formalin in water. The 1 to 8 and 1 to 10 strengths showed no larvicidal effects, and the action of the 1 to 6 solution on the maggots was slight (17 per cent). The bacteriological and chemical results showed the same general tendencies as those found last year, an increased number of bacteria and a reduction of the alkalinity being observed. As the cost of formaldehyde is high, and as strong solutions are required to kill the maggots, the use of this substance is not practical for this purpose.

NITROBENZENE.

Nitrobenzene ($C_6H_5NO_2$), commercially known as oil of mirbane, costs 20 cents per pound and contains 11.4 per cent of nitrogen. The vapors of this liquid are poisonous. Two sets of cage experiments at

Arlington were carried out with emulsions of this substance and fish-oil soap. The strength of these emulsions and the results obtained are given in Table II, series 95 and 101. The larvicidal results, with the exception of series 95, C, were good. The emulsions apparently produced a considerable increase in numbers of the bacteria. An increase of water-soluble nitrogen and ammonia was obtained in all the treated samples. Some further experiments at New Orleans, using the cages which were employed in 1913, gave poor results, as many larvæ escaped (Table III, series 109 and 113). The results of six open-pile experiments are recorded in Table V(series 42, A, B, C, and D, and 52, A and B), and the data for two additional open-pile experiments are given in Table IV (series 47, A and B). Bacteriological and chemical results are given in connection with the last two experiments. The duplicate samples indicate that there was a slight reduction in the number of bacteria and that there was no apparent effect on the manure as shown by the chemical data. All the experiments indicate satisfactory larvicidal results, but the best were those obtained with the largest quantity of fish-oil soap, namely, 1 pound (Table V, series 52, A and B), which killed 93 per cent of the larvæ. This fact suggests that the fish-oil soap is an important constituent of this larvicidal mixture.

OXALIC ACID.

Four cage experiments were carried out with oxalic acid, using 1 and 2 pounds to 10 gallons of water. One experiment with 1 pound gave negative larvicidal results, while the results from three experiments using 2 pounds were as follows: 3 per cent, 60 per cent, and 80 per cent. In the one sample of manure analyzed the bacterial count was reduced, and the ammonia was increased over the control.

PYRIDINE.

Pyridine (C_5H_5N), which is prepared commercially from coal tar, and is also obtained from the distillation of bone oil, is alkaline, contains 17.75 per cent nitrogen, and costs about $1 per pound. This liquid was used in three cage experiments in dilutions of 1 to 100 and in one cage experiment in a dilution of 1 to 500. The results of the cage experiments are shown in Table I (Series 78 and 104). The larvicidal efficiency of the 1 to 100 dilutions was 63 per cent for one cage and 99 per cent for the other two. The 1 to 500 dilutions showed no apparent effect. No consistent action on the bacteria is evident, and the water-soluble nitrogen and the ammonia from the treated samples are higher than from the controls.

In open-pile experiments at New Orleans (Table V, Series 41, A and B) pyridine 1 to 500 was used twice, giving an apparent larvicidal

effect of 99 per cent. Pyridine was used in two open-pile experiments in a dilution of 1 to 1,500 (Table IV, Series 48, A and B), and 8 and 47 per cent of the larvæ were killed.

It is impossible satisfactorily to explain the differences in the larvicidal efficiency of the pyridine in the cage and open-pile experiments where the 1 to 500 dilutions were employed. Different samples of pyridine were used in these two tests, and as the conditions are very different at Arlington and New Orleans the exact larvicidal value of the 1 to 500 dilutions is uncertain. As the 1 to 1,500 is the only dilution that is practical from a cost point of view and the larvicidal effect of this strength was low, this substance is hardly thought to be worthy of further consideration as a larvicide. The extremely disagreeable odor as well as the toxicity of pyridine makes its use in this work objectionable.

PLANT MATERIAL TESTED.

In looking for substances of an organic nature it seemed advisable to test material from several common plants and weeds, especial attention being given to those that are very abundant and therefore cheap.

Dr. Alsberg suggested the use of plants containing saponin, corn cockle being named as a waste product containing considerable amounts of this compound. Agave, a saponin-containing plant growing abundantly in Texas and Florida, was obtained by Mr. W. D. Hunter and was tried in two experiments. Other plant material, some of which contains alkaloids, were also included in the investigation, namely, "blackleaf 40" (an extract of tobacco), larkspur, hellebore, ox-eye daisy, pyrethrum, and stramonium.

Corn cockle.—Corn cockle (*Agrostemma githago*) is present in wheat screenings. The screenings used in this work contained about 43 per cent of corn cockle, and hæmolytic tests [1] showed the presence of considerable saponin. The screenings were ground and then extracted with water for 12 hours. Nine cage experiments at Arlington, using extracts of the screenings containing from 0.3 of a pound to 5 pounds per 10 gallons, were tried, and the highest apparent larvicidal action was 49 per cent. These results varied markedly, and in certain cases no larvicidal effect was obtained. Many bacteriological and chemical analyses showed no change in the number of organisms or the composition of the manure.

Agave.—The roots of several agave or soapweed plants (*Agave lecheguilla*) were macerated and water extracts prepared. Two and one-half pounds of the finely divided roots were extracted for 12

[1] The hæmolytic tests were made by Dr. C. S. Smith, of the Bureau of Chemistry.

hours in 10 gallons of water. This extract was used in two cage experiments and showed a larvicidal action of 82 and 84 per cent. The manure was unaffected chemically, and the bacterial count on one of these samples was considerably higher than the control counts.

"Blackleaf 40."—"Blackleaf 40," an extract of tobacco (*Nicotiana tabacum*), containing 40 per cent of nicotine sulphate, is used to a considerable extent as an insecticide, and it seemed worth while to test its effect on fly larvæ. It was tried in three cage experiments at Arlington, Va., diluted 1 to 50, 1 to 250, and 1 to 500. In none of these cases did it show any larvicidal action.

Larkspur.—Ground seeds of larkspur (Delphinium) were tested, using solutions prepared by treating 1 pound of the ground seeds with 10 gallons of 1 per cent sulphuric acid and allowing them to extract for 12 hours. The extract was applied undiluted, diluted 1 to 5, and diluted 1 to 15. The apparent larvicidal effect varied from 57 to 90 per cent. The bacteria were not affected by the application of the undiluted extract, and the only change in the manure noted was a decrease of alkalinity due to the acid present in the extract added.

Stramonium.—A sulphuric-acid extract of the ground leaves of stramonium (*Datura stramonium*) was prepared by mixing 1 pound of the ground dried leaves with 10 gallons of 1 per cent sulphuric acid and allowing this to stand for 12 hours. This extract was employed undiluted, diluted 1 to 5 and 1 to 15. The larvicidal results were not as satisfactory as those obtained above where larkspur extracts were employed. The bacterial count on manure treated with the undiluted extract was lowered somewhat, and the reaction showed a slight reduction in alkalinity due to the sulphuric acid present in the extract applied.

Hellebore.—Roots of hellebore (*Veratrum album* and *Veratrum viride*) were used both in a ground and in a powdered condition. As the following results will show, the powdered hellebore proved to be the more effective. Both 1 per cent sulphuric acid and water extracts of ground hellebore were used in cage experiments at Arlington (Table VI, Series 82, 92, 102, and 103), and the results indicate a high larvicidal action.

TABLE VI.—*Destruction of fly larvæ in horse manure. Results with ground hellebore; cage experiments, Arlington, Va., 1914.*

Series.	Treatment of 8 bushels of manure, using 10 gallons of liquid.	Flies emerged.	Apparent larvicidal effect.	Number of bacteria per 1 gram manure, calculated to dry weight.	Manure, total nitrogen.	Water extract.		
						Alkalinity, N/20 HCl per 100 c. c. (5 grams of manure).	Water-soluble nitrogen.	N as NH_3, Folin method.
		Number.	*Per cent of control average.*	*Millions.*	*Per cent.*	*C. c.*	*Per cent of total nitrogen.*	*Per cent of total nitrogen.*
82 A	Hellebore (ground), 1 pound to 10 gallons 1 per cent H_2SO_4, undiluted	10	94	423	0.526	7.15	27.76	2.85
82 B	Same as foregoing, diluted one-fifth	33	78	576	.688	10.25	24.42	2.76
87 A	Control (water only)	192	....	506	.695	11.25	28.20	1.87
87 B	Do	114	....	498	.618	15.40	27.18	2.59
87 C	Do	145	....	....	....	....	....	....
	Control average	150	....	....	....	....	....	....
92 A	Hellebore (ground), 1 pound to 10 gallons 1 per cent H_2SO_4, undiluted	35	89	....	.456	7.50	27.19	2.63
92 B	Same as foregoing, diluted one-third	18	94.3	236	.470	6.15	23.83	3.40
93 A	Control (water only)	551	....	29.8	.863	9.15	29.32	1.85
93 B	Do	333	....	12	1.45	13.25	43.72	3.25
93 C	Do	67	....	159	.905	14.15	31.05	2.87
	Control average	317	....	....	....	....	....	....
102 A	Hellebore (ground), ½ pound to 10 gallons 1 per cent H_2SO_4	315	90	....	.526	(acid).50	25.67	2.85
102 B	Do	267	92	....	.498	(acid).50	21.49	3.40
103 A	Hellebore (ground), ½ pound to 10 gallons water	58	98+	....	.568	3.50	22.70	....
103 B	Do	39	99	....	.554	6.15	28.34	1.32
106 A	Control (water only)	4,489	....	19.6	.572	4.25	25.00	2.10
106 B	Do	1,936	....	27.1	.561	4.65	26.02	1.41
	Control average	3,212	....	....	....	....	....	....

The water extract proved to be just as satisfactory as the acid extract. Table III, series 108 and 112, shows additional results from some cage experiments at New Orleans, in which the effectiveness appeared to be very low, but the results are of doubtful value for the same reasons pointed out on page 8. It is very difficult to explain why so little larvicidal effect was found in series 112 in view of the uniformly good results in other cages and open piles.

Results from the application of water extracts of ground hellebore applied to open piles are shown in Table IV, series 44 to 48, inclusive. When used at the rate of one-fourth of a pound to 10 gallons, it had a variable larvicidal action, never above 50 per cent. At the rate of three-eighths of a pound to 10 gallons the results were, on the average, somewhat higher, but none was above 70 per cent; at the rate of one-half pound to 10 gallons series 44, A and B, Table IV, showed 59 and 62 per cent action; 48, C and D, showed 44 and 62 per cent; and Table V, series 43, A and B, showed 99 per cent effectiveness.

Powdered hellebore was used in several open-pile experiments at New Orleans, and the results, as shown in Tables IV and V, indicate that the application of one-half pound per 10 gallons was uniformly favorable, the percentages varying from 88 to 99, the average of 12 open-pile experiments being 95.5 per cent. With three-eighths or one-fourth pound of powdered hellebore to 10 gallons the larvicidal effects were lower but still showed considerable action. It is evident

that the larvicidal value varies with the amount of powdered hellebore used, but when applied at the rate of one-half pound or more to 8 bushels of manure it will be efficient. It is not known how hellebore acts as a larvicide. At present no information is available as to whether it has any effect on the eggs or pupæ of the house fly.

The effects of the presence of fly maggots in a pile of manure is very strikingly shown by comparing figures 2 and 3 of Plate I. The pile treated with hellebore has remained normal in shape and appearance (Pl. I, fig. 3), while the maggots have worked the untreated pile shown (Pl. I, fig. 2), the manure being finely divided and the pile scattered by the feeding and migration of the larvæ.

The bacterial counts of manure in the cages (Table VI) treated with 1 per cent sulphuric-acid extracts of hellebore showed no bactericidal effects.

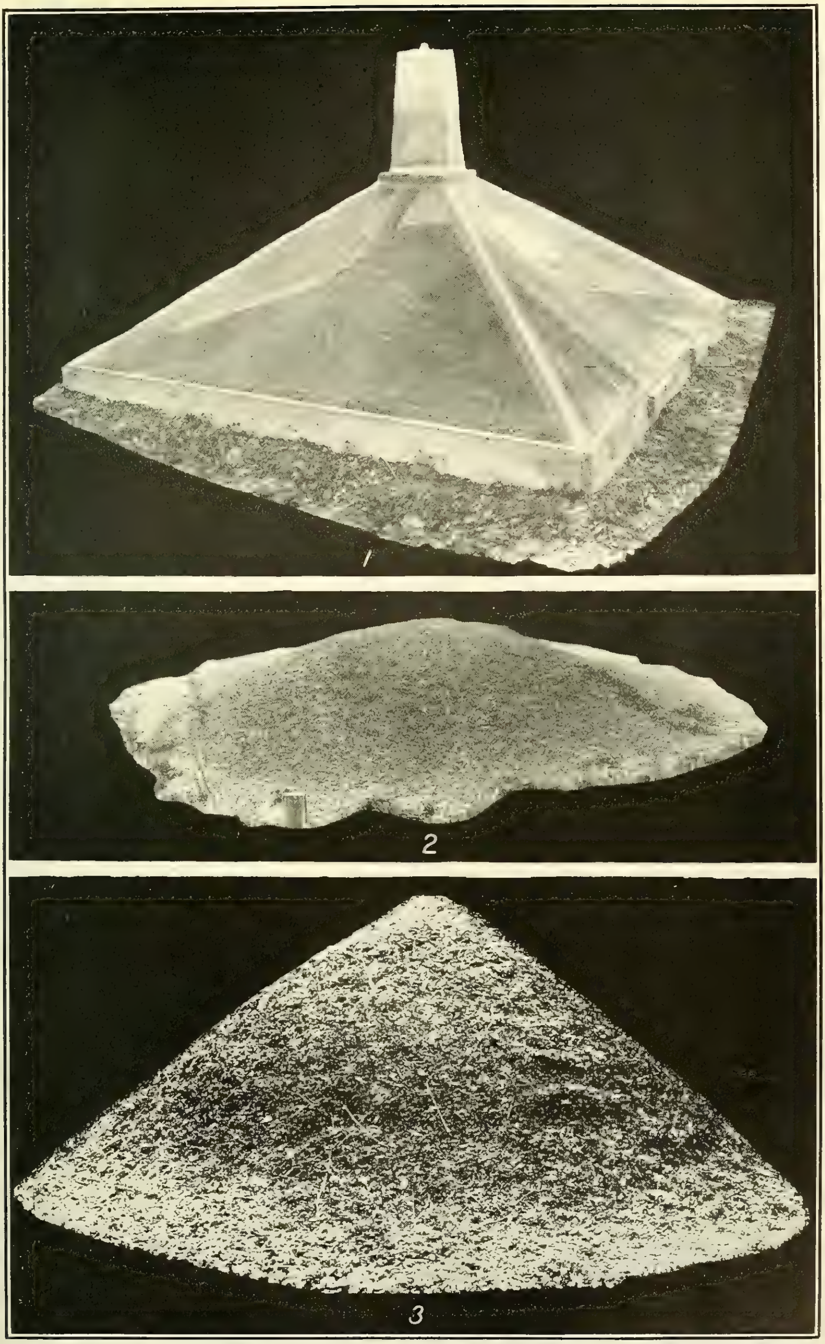
The bacterial counts of the open piles (Table IV) did not show any consistent action, either stimulating or bactericidal. During the season's work nitrites and nitrates were detected only in open-pile experiments 53, A, B, C, and D, which were treated with hellebore, and it is therefore apparent that the hellebore extract is not toxic to the nitrifying organisms in this environment.

Three series of temperatures taken daily of control piles and those treated with pyrethrum, pyridine, and hellebore further indicated that there was no permanent injury to the bacteria present in the piles treated with the last substance. In the first series the temperature was 13° below the control on the second day, but on the third day was again the same as the control. Neither of the other series showed any depression of temperature at the start, and the piles seemed to undergo a normal fermentation, indicating, as do all the data, that the treatment with hellebore does not reduce the fertilizing value of the manure.

The chemical data on both the cage and open-pile experiments show that the manure was unaffected by the hellebore treatment. When 1 per cent sulphuric-acid extracts were used in the cage experiments at Arlington, a reduction in alkalinity due to the added acid was found. It is, therefore, evident that powdered hellebore can be applied, using one-half pound to 10 gallons of water, without injuring the fertilizing value of manure as determined by chemical and bacteriological examination. Furthermore, a laboratory test has shown that hellebore readily decomposes in manure. A sample of manure treated with hellebore at the rate of one-half pound per 8 bushels when tested microscopically and colorimetrically gave positive results, but after 30 days' fermentation both were negative.

The alkaloidal content of the commercial green and white hellebore is known to vary from about 0.2 per cent to 0.9 per cent of total alkaloids.[1] In Table IV, series 53, the hellebore used was of known

[1] Data obtained from Insecticide Laboratory, Bureau of Chemistry, U. S. Department of Agriculture.



DESTRUCTION OF FLY LARVÆ IN HORSE MANURE.

FIG. 1.—Type of cage used for catching flies from treated manure piles. FIG. 2.—Settled and finely divided condition of an untreated pile, heavily infested with maggots. FIG. 3.—A hellebore-treated pile of same source and volume as figure 2. Hellebore, by preventing growth of fly maggots, prevented the disintegration of the heap. (Original.)

alkaloidal content; the two samples contained 0.25 and 0.41 per cent, respectively, and no differences in larvicidal action were evident.

The powdered hellebore used in the other experiments at New Orleans contained 11.49 per cent of ash, 1.04 per cent of total nitrogen, and about 0.2 per cent of total alkaloids. The ground hellebore used contained 29.39 per cent of ash, 1.08 per cent total nitrogen, and 0.2 per cent total alkaloids. It is therefore likely that commercial powdered hellebore of reasonable purity will be effective as a larvicide if applied as directed (p. 19).

General discussion of hellebore.—There are three plants which are popularly called hellebore, namely, *Veratrum album*, *Veratrum viride*, and *Helleborus niger*. The term "hellebore" is correctly applied only to *Helleborus niger*, which grows in Europe and is not at the present time a commercial product in this country. The white and the green are the two commercial varieties, the white being largely imported, and the green the American plant. For insecticidal work these two varieties are considered equally valuable. The American hellebore (*Veratrum viride*), called "swamp hellebore," "Indian poke," and "itch-weed," is a common plant in wet ground and grows over a considerable area of the United States. The properties of this plant are said to be similar to those of white hellebore. A number of alkaloids are claimed to have been separated from these two plants, but there is some uncertainty as to their identity and activity. Powdered hellebore, both the white and the green, is extensively used as an insecticide against the currant worm and to kill various insects around the roots of plants. Both varieties of hellebore are used in medicine to some extent.

OTHER PLANT MATERIAL.

Oxeye daisy.—Tests were made with the ground flowers of the oxeye daisy (*Chrysanthemum leucanthemum*), using 1 pound to 10 gallons of 1 per cent sulphuric acid. The material was extracted for 12 hours, and the extract was used undiluted and diluted 1 to 5. The larvicidal results were practically negative in both cases, but as the manure used in this experiment was lightly infested with larvæ and the results hardly warrant any definite conclusions. Bacteriological and chemical examinations were made of the manure treated with the undiluted extract. The bacterial count of the manure was somewhat lower than the controls, while the only noticeable change in chemical composition was a decrease in the alkalinity due to the acid in the extract added. The oxeye daisy contains a volatile oil but no alkaloid has been found.

Pyrethrum.—Pyrethrum (*Crysanthemum cinerariaefolium*) powder was tried and two results from open-pile tests at New Orleans show that solutions containing 0.5 pound per 10 gallons of water had no larvicidal action (Table V, series 52, C and D). Pyrethrum contains a volatile oil, and an alkaloid has been detected by one or two investigators.

DISCUSSION OF DIAGRAM (FIG. 1).

From the results of some open-pile experiments at New Orleans the comparative cost and larvicidal efficiency of some of the more favor-

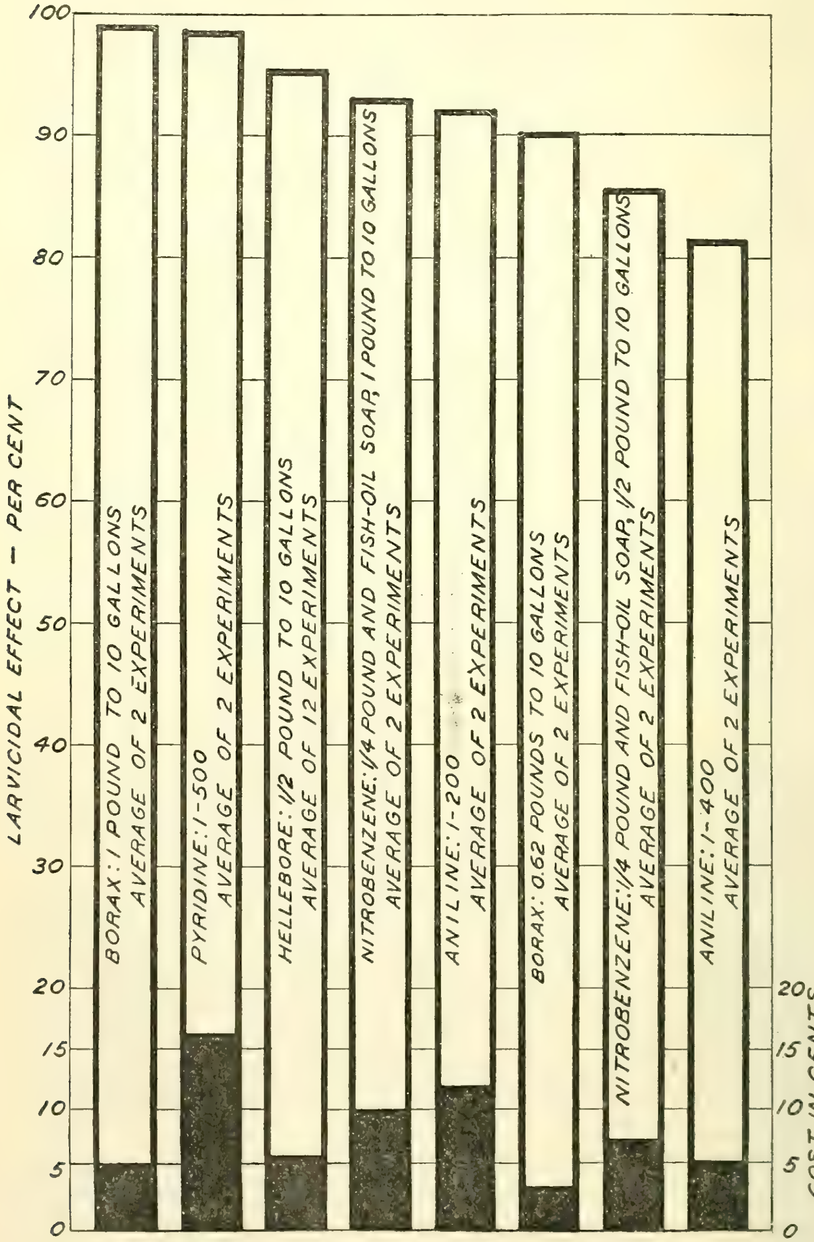


FIG. 1.—Diagram showing larvicidal effect and comparative cost of the treatment of 8 bushels of manure by various chemicals. (Original.)

able substances have been computed and are shown graphically in figure 1. Most of these calculations are based on an average of but

two experiments and are therefore to be regarded as only tentative. However, the results of the cage experiments are in general agreement with the findings as given in the diagram.

It will be noted that the highest larvicidal effect was obtained with borax, using 1 pound to 8 bushels. The least expensive treatment was that with 0.62 pound of borax, although the larvicidal action was only 90 per cent. The next cheapest was hellebore, which costs 5½ cents for one-half pound of the powdered roots, and the average of 12 experiments showed a larvicidal action of 95.5 per cent. The hellebore treatment at the foregoing rate costs more than that with 0.62 of a pound of borax but shows a greater efficiency.

In comparing the cost we have assumed that borax can be obtained at 5 to 6 cents per pound in 100-pound lots and that hellebore can be purchased at 11 cents per pound in like amounts. The price of both is subject to considerable variation. The results in general indicate that the larvicidal action varies with the amounts used, except in the case of nitrobenzene, where the value seems to depend on the proportions of nitrobenzene and soap in the emulsion.

It will be noted that pyridine and aniline, when used in amounts sufficient to kill a high percentage of the larvæ, are quite expensive, and for this reason their use can not be considered practical.

APPLICATION OF HELLEBORE TO MANURE.

Powdered hellebore should be mixed with water at the rate of one-half pound to 10 gallons and the solution thoroughly stirred and allowed to stand for several hours in a barrel or other container. In order to obtain the most satisfactory results, the manure should be sprinkled with the foregoing solution immediately on removal from the barn. The sprinkling may be done with a watering can or similar device, using 10 gallons to 8 bushels of manure, taking care that all of the hellebore comes in contact with the manure and paying particular attention to the outer edges of the pile. In estimating the amount of solution to be employed it may be assumed that 2 bushels of manure per horse is the daily output of the stable. This is a liberal estimate, and in many stables the daily output is much less.

EFFECT OF HELLEBORE ON PLANTS AND CHICKENS.

During November, 1914, a series of tests was started at both Baton Rouge and New Orleans, La., to determine whether hellebore, when applied in considerable amounts, exerts injurious effects on plant growth. The plants grown included cabbage, lettuce, oats, turnips, radishes, potatoes, wheat, and mustard, half of each plat being fertilized with hellebore-treated manure, and the other half receiving untreated manure. At the present time no injurious

effect is noticeable from the experiments at either New Orleans or Baton Rouge.

The cooperation of Mr. George L. Tiebout, of the Louisiana Experiment Station, Baton Rouge, and of Mr. W. G. Taggart, of the Audubon Park Sugar Station, New Orleans, in connection with these tests was of great assistance.

As chickens and other farm animals are known to peck at, or consume, certain parts of manure, tests were made by Mr. E. R. Barber, placing hellebore-treated manure in coops with chickens and using as controls chickens in a coop with untreated manure. Thirty-eight one-hundredths of a pound of powdered hellebore was mixed with 4 bushels of manure and placed in one coop with four chickens, and every three days another lot of the manure similarly treated was placed in this coop. The manure which was used contained fly maggots, consequently the chickens were eager to peck through it. In addition, the chickens, in both cases, were fed on cracked corn and were given fresh water. The appearance of the chickens was noted daily, and the test has been conducted for several weeks with no apparent ill effect due to hellebore.

SUMMARY.

The larvicidal efficiency of both inorganic and organic substances was tested and bacteriological and chemical examinations of horse manure to which many of these substances were applied are reported.

The following inorganic substances were tried:

- Arsenical dip.
- Chlorid of lime.
- Epsom salts.
- Lime-sulphur.
- Sulphuric acid.

Of these substances arsenical dip was the only one which when used in amounts considered practical destroyed the larvæ of the house fly. Because of its poisonous nature the use of arsenical dip as a larvicide is not recommended.

The following organic substances were tested:

- Aniline.
- Beta-naphthol.
- Cresylic acid.
- Para-dichlorobenzene.
- Formaldehyde.
- Nitrobenzene.
- Oxalic acid.
- Pyridine.

Aniline, pyridine, and nitrobenzene, when used in certain dilutions, gave satisfactory larvicidal results, but the cost precludes their use.

The larvicidal action of the following plant materials was tested:

Plant material containing saponin—

Corn cockle (*Agrostemma githago*).
Agave (*Agave lecheguilla*).

Plant material containing alkaloids—

"Black leaf 40"—tobacco extract (*Nicotiana tabacum*).
Larkspur (Delphinium).
Stramonium (*Datura stramonium*).
Hellebore (*Veratrum album* and *Veratrum viride*).

Other plant material—

Oxeye daisy (*Chrysanthemum leucanthemum*).
Pyrethrum (*Chrysanthemum cinerariaefolium*).

Powdered hellebore proved the most efficient and practical of all the substances tested.

COMPARATIVE ADVANTAGES OF BORAX AND HELLEBORE.

Borax, which was shown in Bulletin No. 118 to be an effective larvicide, is obtainable in all parts of the country, and the cost of treating manure at the rate of 0.62 pound of borax per 8 bushels is 0.42 cent per bushel.

Powdered hellebore, using one-half pound to 10 gallons of water and applying this to 8 bushels of manure, is also an effective larvicide and exerts no injurious action on the fertilizing value of the manure as determined by bacteriological and chemical analyses, and no injurious action on plants has been detected in any of the field tests. Hellebore is used as an insecticide and is obtainable in most cities and agricultural districts. The cost of this treatment is 0.69 cent per bushel of manure.

While borax may be applied to manure at the foregoing rate and the treated manure may be added to the soil at the rate of 15 tons to the acre without injuring vegetation, nevertheless excessive quantities of borax may be applied to manure through carelessness, and injury to vegetation may in consequence result. In the light of this year's experiments it seems advisable to recommend borax as a larvicide for the treatment of outhouses, refuse piles, and all other places where flies may deposit eggs. However, on account of the possible carelessness previously mentioned, and because large quantities of manure are sometimes used by truck growers, it seems best to guard against possible injury to vegetation by recommending powdered hellebore for the treatment of manure, since no injury can arise from the use of excessive quantities, as it is entirely decomposed in the course of the fermentation of the manure.

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 246

Contribution from the Office of Public Roads, Logan Waller Page, Director.
July 24, 1915.

VITRIFIED BRICK PAVEMENTS FOR COUNTRY ROADS.

By VERNON M. PEIRCE, *Chief of Construction*, and CHARLES H. MOOREFIELD, *Senior Highway Engineer.*

CONTENTS.

INTRODUCTION.

A clay product closely resembling our present-day brick was among the earliest materials used for paving streets and roads. The first brick pavement constructed in this country, however, dates back no further than 1872, and to Charleston, W. Va., belongs the distinction of having been the first American city to employ brick for paving.

For a number of years after being introduced into this country the use of paving brick was principally confined to city streets, and, owing to frequent inferiority in the quality of the brick and lack of care in construction, very few of the early pavements proved satisfactory. Even now, after the experience of 40 years has demonstrated that it is entirely practicable to construct satisfactory brick pavements when proper care is exercised, and that much waste results from the use of poor materials or faulty construction, instances can frequently be found where comparatively new brick pavements have wholly or partially failed from causes which might easily have been prevented.

Country roads paved with vitrified brick are becoming quite common in many of our States, and, owing to the general satisfaction

which these roads are giving when properly constructed, it is probable that their mileage will continue to increase rapidly. The principal advantages which brick roads possess may be stated briefly, as follows: (1) They are durable under practically all traffic conditions; (2) they afford easy traction and moderately good foothold for horses; and (3) they are easily maintained and kept clean.

The principal disadvantage is the high first cost. The defects which frequently result from lack of uniformity in the quality of the brick or from poor construction are usually to be traced indirectly to an effort to reduce the first cost or to a popular feeling that local materials should be used, even when of inferior quality.

This bulletin purposes to furnish information relating to the construction of brick roads and to supply suggestions for aiding engineers in preparing specifications under which such work may be satisfactorily performed. One of the most essential features of the construction of brick pavements is the selection of the brick, since the success or failure of such pavements depends to a large extent on the character of the material used. In order that the significance of the varying physical characteristics observed in brick manufactured under different conditions may be more readily understood, a brief discussion of the raw materials and processes used in the manufacture of brick will be given.

THE RAW MATERIALS.

Paving brick are made from shales and fire clays. The "lean" or less refractory varieties of these materials, which are found in the carboniferous deposits broadly distributed throughout the United States, are best adapted for this purpose.

Shales frequently occur in such quantity and are so located that they may be readily excavated by means of a steam shovel or other mechanical device. Occasionally the deposits are comparatively thin and underlie other material, making it necessary that they be mined. Fire clays are usually found interstratified with coal deposits which may or may not be workable, and must, therefore, generally be mined. The principal difference between fire clays and shales, in so far as the manufacture of brick is concerned, is essentially a difference of color in the finished product. The shales always contain iron in some form, and brick made of shale are usually red. Fire clays are free from iron and should produce a light-colored brick. Some low-grade fire clays, however, may be darkened by certain firing conditions too complicated to be discussed in detail here.

Shales and fire clays as they occur in nature are not always well suited for use in the manufacture of paving brick, but must frequently be subjected to some modifying treatment before being used. In general, deposits of these materials occur in layers or strata, and

the different strata are almost always slightly dissimilar in both physical and chemical composition. By carefully mixing the materials from different strata or from different parts of the bank, therefore, a resulting material of the desired character may usually be obtained. But it not infrequently happens that in order to secure the best results sand or surface clay must be added in an amount depending on the relative "leanness" or "fatness"[1] of the material used. In this connection it may be noted, also, that a chemical analysis of a given fire clay or shale does not necessarily indicate its fitness or unfitness for paving brick. The reason for this is that the quality of the brick after "firing" is no less dependent on the physical arrangement of the minerals than on the chemical composition of the material.

THE MANUFACTURE.

The general processes of manufacture are the same for both fire clays and shale. The raw material in either case is crushed to comparatively small fragments and conveyed by some convenient means to a grinding machine, known in the industry as a dry pan. Briefly, this machine consists of a solid iron plate, approximately 5 feet in diameter, surrounded by a perforated iron surface about 2 feet wide. Outside the perforated surface is a rim some 15 inches in height which serves to prevent the material from escaping otherwise than through the perforations. Upon the solid plate rest two massive crushers or mullers, each weighing from 2½ to 3 tons. The pan is revolved rapidly, causing the mullers to rotate by friction. The material is ground between the mullers and the plate and thrown out by centrifugal force toward the rim, where it escapes through the perforated surface into an elevator, by means of which it is conveyed to the screens.

The particles too large to pass the screens, which should not exceed three-sixteenths inch in mesh, are returned to the dry pan, while the screened material is passed to the mixing machine or pug mill by means of conveyors. In the pug mill, water is admixed with the clay to form a stiff mud, which is fed continuously into the brick machine proper.

The brick machine is an extremely heavy mechanism. It consists essentially of an auger or propeller conveyer, a tapering barrel, and the die or former. The material is forced by means of the auger conveyer into the tapering barrel, which terminates in the die, and issues from the die in a solid column under heavy pressure. For "side-cut" brick this column is approximately 4½ inches by 10

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[1] "Leanness" and "fatness" refer respectively to the lesser or greater amount of silicate present in the material.

inches in cross section, and the brick are formed by cutting through the column, by means of an automatic device, at intervals of about $3\frac{1}{2}$ inches. For "end-cut" brick the column has a cross section approximately 4 inches by $4\frac{1}{2}$ inches and is cut into sections about 10 inches long.

Paving brick, whether end or side cut, have usually in the past been re-pressed. This process smooths the surfaces, rounds the corners, and forms on one side of each brick small lugs which serve to produce uniform spacing between the successive courses of the pavement. Suitable lugs may also be formed at the time the brick are cut, and the process of re-pressing is then omitted. Much discussion has taken place as to which of these methods produces the better brick, and each method has many advocates. Entirely satisfactory pavements have been made from both re-pressed and unrepressed brick under widely different conditions, and it is very doubtful if the failures which have been observed in connection with either type could rightfully be attributed to this particular feature in the process of manufacture.

Special shapes, such as nose brick for use next to car tracks, and hillside block, which have one side thicker than the other and which are used on steep grades in order to give the pavement a rough surface, may be made either by special die or special re-press molds.

The next step in the process of manufacture consists in drying the brick. In a properly systematized plant the brick are stacked upon drier cars as they leave the presses in such manner as to permit a free circulation of air between them. The loaded cars are immediately run into a tunnel dryer, the temperature of which is maintained at about 100° F. at the entering end. As cars containing "green" brick enter one end of the tunnel, which is usually more than 100 feet long, other cars containing dry brick are being removed at the opposite end. Air circulation in the dryer is effected by means of fans or high stacks. During drying the brick lose an amount of moisture equivalent to from 15 to 20 per cent of their own weight.

The brick leave the dryer ready for burning, which is the last and undoubtedly the most important step in the process of manufacture. Upon the burning depends largely the quality of the finished product, and it requires the greatest skill so to regulate the temperatures and firing periods as to obtain the best results from a given material. Experience alone can demonstrate the manner in which the burning must be modified in order to suit varying sets of conditions. The kilns in which the burning is done are made of brick and are provided with numerous furnaces. The brick are placed in the kilns so as to permit a free circulation of the gases of combustion and the heated air.

PHYSICAL CHARACTERISTICS.

GENERAL REQUIREMENTS.

Paving brick should be uniform in size, reasonably perfect in shape, free from ragging, due to friction in the die, and from deep kiln marks, caused by impressions from overlying brick in burning. They should be tough in order to resist crushing, hard in order to resist abrasion, and uniformly graded in order that the pavement may wear evenly. Each brick should be homogeneous in texture and free from objectionable laminations or seams. Fire cracks, caused by too rapid firing, should be limited in number and extent, and the entire brick should be vitrified and should contain neither unfused nor glassy spots.

COLOR.

The color is a valuable guide in inspecting brick from the same plant, but it is of little importance when the brick to be compared are from different factories. For brick manufactured from a particular raw material the color indicates, in a measure, the temperature to which they have been subjected, provided they have been burned under identical conditions. Ordinarily, the darker the color, the higher the temperature and, presumably, the better the brick. The surface color of brick may be very misleading, however, and the color of the interior should be used in making comparisons.

SPECIFIC GRAVITY.

The specific gravity of paving brick was formerly considered of importance in judging their fitness for use in pavements. But it has since been generally conceded that a knowledge of the specific gravity is of comparatively little value. The specific gravity of shale brick is ordinarily between 2.20 and 2.40, and of fire-clay brick between 2.10 and 2.25.

ABSORPTION.

The absorptive power of brick, like their color, is a matter of very slight importance, except for comparing specimens manufactured under identical conditions. It is true that the porosity of the brick increases with the power of absorption, but it is very doubtful if any paving brick possessing an objectionably high absorptive power could pass even a very casual inspection. In other words, a high degree of porosity always manifests itself in other ways more clearly than in the ability of the brick to absorb water.

CRUSHING STRENGTH.

The crushing strength of good paving brick varies from 10,000 pounds to 20,000 pounds per square inch when the load is applied

uniformly over the entire top surface of the test specimen, and may be much greater if the area over which the load is applied is less than that of the top surface. Since paving brick in use are seldom required to withstand a pressure of more than about 2,000 pounds per square inch, and since inferior brick may possess relatively very high resistance to crushing, a knowledge of the crushing strength is clearly of little value in comparing the relative excellence of different makes of brick. It is, therefore, usually considered unnecessary to specify a definite requirement as to the crushing strength of paving brick.

TESTING THE BRICK.

Definite methods of testing paving brick have been in general use for only a comparatively few years and have only recently undergone a pronounced change. The object of all tests is to determine whether or not a given quality of brick is suitable for use in constructing pavements and to furnish a basis for comparing different classes of brick. The methods have, therefore, been repeatedly changed, not only in order to make the results obtained indicate more definitely the quality of the brick, but also with a view to establishing uniformity, so that results obtained in different laboratories may be intelligently compared. A discussion of the most important tests follows in more or less detail.

FIELD TEST.

The general appearance of a paving brick is, to an experienced eye, a valuable indication of its quality and will frequently suggest the advisability of applying routine tests to some particular part of a shipment. Unfortunately the knowledge gained from experience with one kind of brick can not be safely relied upon in inspecting other brick made by a different process or from a different class of raw material. A further limitation to this method of testing lies in the fact that the results obtained do not admit of numerical evaluation, and can not, therefore, be very accurately described. This test is nevertheless valuable, and since no apparatus other than a hand hammer is needed, it can always be employed.

The test consists simply in making a careful inspection of the brick individually and collectively. The size is tested by making measurements, the shape by arranging a number of brick in the order in which they are intended to be placed, and the quality by an examination of both the exterior and interior of a number of samples.

TRANSVERSE TEST.

The transverse strength of a brick is determined by supporting it upon two knife edges and applying a load on the opposite side and

midway between the supports by means of a third knife edge. The load is gradually increased until rupture occurs, and the result of the test is expressed in terms of the ratio $\frac{3Pl}{2bd^2}$, called the modulus of rupture. In the above ratio P represents the breaking load in pounds, while l, b, and d represent, respectively, the distance between supports, the breadth of the specimen, and the depth of the specimen, all measured in inches.

The modulus of rupture for good paving brick usually lies between 2,000 and 3,000 pounds per square inch, and frequently varies considerably even with carefully selected specimens which have been manufactured under identical conditions.

RATTLER OR ABRASION TEST.

The rattler or abrasion test is undoubtedly the most important of the tests made on paving brick at present. In making this test the specimen brick are subjected to destructive influences very similar to those encountered in actual service, and the results obtained, therefore, indicate very closely the effect which traffic may be expected to produce on a pavement constructed of similar brick. The methods of making the test, of which there were formerly a great many, have undergone repeated changes in order that service conditions may be more nearly approached, and also in an effort to bring about uniformity, so that the results obtained may be of the greatest possible scientific value. The method which is now proposed by the subcommittee on paving brick of the American Society for Testing Materials may be briefly described as follows:

The apparatus necessary for making the test, ordinarily called the rattler, consists of a 14-sided barrel of regular polygonal cross section supported on a suitable frame and fitted with the necessary driving mechanism. The staves, each of which forms a side of the barrel, are made of 6-inch 15.5-pound structural steel channels $27\frac{1}{4}$ inches long. These staves are double bolted to the cast-iron heads of the barrel, which are provided with slotted flanges for holding the bolts. Cast-iron wear plates are bolted to the inside of the barrel heads. The inside diameter of the barrel is $28\frac{3}{8}$ inches.

In this barrel is placed what is known as the abrasive charge. This charge consists of two sizes of cast-iron spheres having respective diameters of $3\frac{3}{4}$ inches and $1\frac{7}{8}$ inches and weighing, respectively, 7.5 pounds and 0.95 pound when new. Ten of the larger spheres are used, and the number of the smaller spheres is made such that the weight of the entire charge will approximate 300 pounds. The individual larger spheres are discarded whenever their weight falls to 7 pounds or less and the smaller spheres when they become suffi-

ciently worn by usage to pass through a circular opening having a diameter of $1\frac{3}{4}$ inches.

The test is made by placing a charge of 10 dry brick in the barrel, together with the abrasive charge, and then revolving the barrel 1,800 times. The number of revolutions per minute is not permitted to fall below $29\frac{1}{2}$ nor to exceed $30\frac{1}{2}$, and the operation is made continuous from start to finish.

The results of the test are reckoned in terms of the loss in weight sustained by the brick, and this loss is expressed as a percentage of the original weight of the brick tested. In determining the loss in weight, no piece of brick which weighs less than 1 pound is considered as having withstood the test.

Good paving brick will ordinarily lose from 18 per cent to 24 per cent of their original weight in the rattler test, and specifications concerning this loss should be prepared with a view to the character of the traffic for which the pavement is designed.

It is also advisable to require a minimum as well as a maximum percentage of loss which any specified sample of the brick may sustain. This is done in order to insure against too much variation between the softest acceptable brick and the hardest brick which may be supplied.

CONSTRUCTION.

PREPARING THE ROADBED.

In forming a roadbed upon which a brick pavement is to be constructed, the essential features to be considered are (1) thorough drainage, (2) firmness, (3) uniformity in grade and cross section, and (4) adequate shoulders.

Thorough drainage can be secured for any particular road only by means of a careful study of the local conditions which affect the accumulation and "run-off" of both the surface and ground water. These conditions vary considerably even in the same locality, and no set of rules can be given which would cover all cases. For example, the material composing the roadbed may be springy, and in this case tile underdrains will probably be necessary. On the other hand, extremely flat topography may make it necessary to elevate the grade considerably above the surrounding land. The nature of the soil, the topography, and the rainfall must all be considered if a system of drainage is to be planned properly.

The second requirement, firmness, can be secured only after the road has been properly drained. Soils which readily absorb moisture can not be properly drained in wet weather and should not be permitted to form a part of the subgrade. In order that the subgrade may be unyielding, it is also necessary that the roadbed be thoroughly compacted. In forming embankments the material should be put

down in layers not over 8 inches thick, and each layer should be thoroughly rolled. In excavation care should be exercised, if the material is earth, not to permit plows or scrapers to penetrate below the subgrade. The subgrade in both excavation and embankment should be brought to its final shape by means of fine grading with picks and shovels and rolling.

When completed the subgrade should be uniform in grade and cross section, otherwise the foundation must be made unnecessarily thick where depressions occur, in order that its grade and cross section may be uniform and its thickness not less at any point than that required. The subgrade should be repeatedly rolled and reshaped until the desired shape is secured. If curbs are constructed independent of the base they should be set before the final finishing, in order that they may be made to serve as a guide for this work.

The shoulders should never be less than 4 feet wide and should consist of some material which compacts readily under the roller and does not readily absorb water. Not infrequently one of the shoulders is made sufficiently wide to form an earth roadway parallel to the brick pavement. Such an arrangement serves to relieve the pavement of considerable traffic during favorable seasons and also affords some advantage to horse-drawn traffic. The general method of constructing shoulders for brick roads is not essentially different from that employed for other types of pavements.

CURBING.

All brick pavements should be supplied with strong, durable curbing, both on the sides and at the ends. Otherwise the marginal brick will soon become displaced by the action of traffic, and their displacement will, of course, expose the brick next adjoining, so that deterioration might eventually spread over the entire pavement. Properly constructed curbing, on the other hand, will hold the pavement as in a frame and enable the brick to present their combined resistance to the destructive influences of traffic.

Satisfactory curbs may be constructed of stone, Portland cement concrete, or vitrified clay shapes made especially for this purpose. Wood has also been used for curbs to a limited extent, but when it is considered that the life of a brick pavement under ordinary conditions should far exceed the life of any wood curb which might be devised, the economy of employing a more durable material is readily apparent.

Stone curbing may be made from any hard, tough stone which is sufficiently homogeneous and free from seams to admit being quarried into blocks not less than 4 feet long, 5 inches thick, and 18 inches deep. On account of their ordinarily homogeneous structure,

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granite and sandstone are probably more used for curbs than any other kind of stone.

All stone curbing should be hauled, distributed, and set before the subgrade is completed. The individual blocks should be not less than about 4 feet long, except at closures, and should ordinarily have a depth of from 16 to 24 inches, depending on soil conditions and on whether the curb is to project above the surface, forming one side of the gutter. The neat thickness need never be greater than 8 inches and, where the traffic conditions are not severe and the quality of the stone is good, a thickness of 6 inches will ordinarily prove satisfactory. Stone curb should always be set on a firm bed of gravel, slag, or broken stone, not less than 3 inches thick, or on unusually firm earth, and should be provided with a backing of the

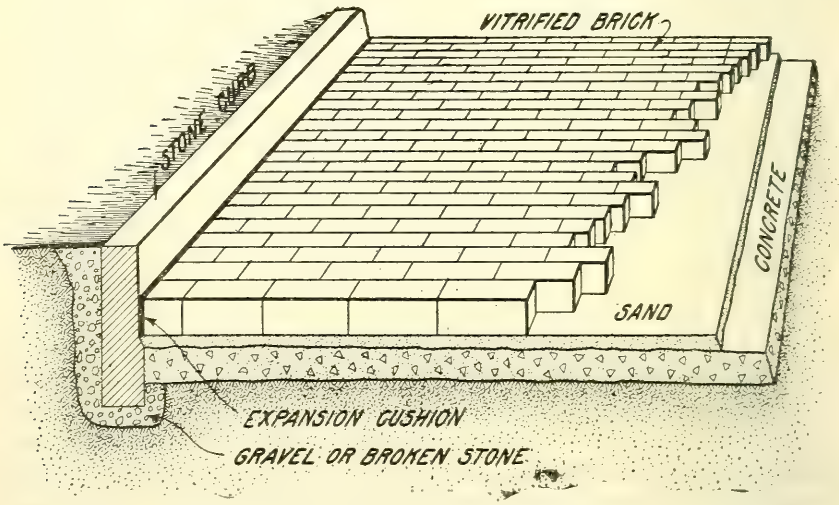


FIG. 1.—Proper method of constructing stone curb.

same material on the shoulder or sidewalk side. Figure 1 shows a typical stone curb in place.

Where suitable stone is not readily available or when from any cause the cost of stone curbing would prove excessive, a curb constructed of Portland cement concrete may frequently be advantageously used. Concrete curbs may be constructed alone or in combination with either a concrete gutter or a concrete foundation. When constructed alone they should have approximately the same cross-sectional dimensions as stone curbs and should be constructed in sections about 8 to 10 feet in length. Figures 2 and 3 and Plate I show the three common types of concrete curbs.

Vitrified clay curbing should be set in much the same manner as that described for stone curbing. The principal additional requirement is that, since vitrified clay is a lighter material than stone and

the curb sections are ordinarily shorter, the bedding must be made correspondingly more secure in order to prevent displacement.

THE FOUNDATION OR BASE.

A firm, unyielding foundation is one of the most essential features of a brick pavement. This fact can be more readily appreciated when it is considered that the surface of a brick pavement is made up of small individual blocks, any one of which might be easily forced down, causing unevenness in the surface, if the foundation were poor; and since the ability of the pavement to resist wear depends very largely on the smoothness of the surface, every reasonable precaution should be taken to prevent any unevenness from developing.

The proper type of foundation or base depends largely on the material composing the subgrade and the character of traffic for which the

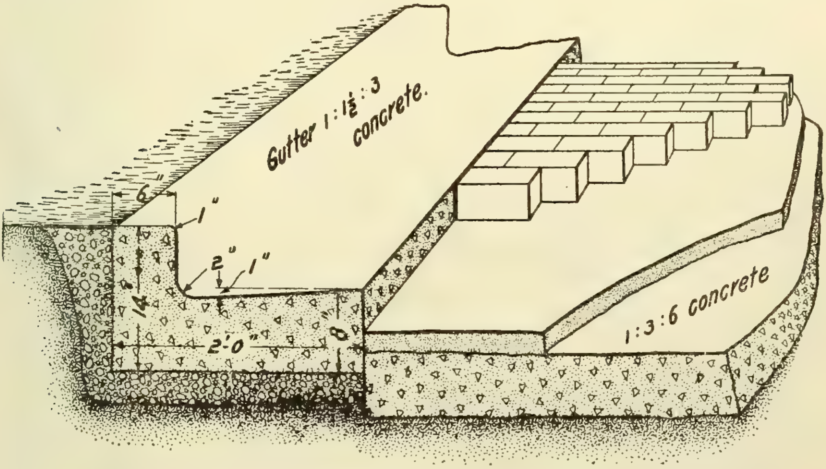


FIG. 2.—Concrete curb and gutter combined.

road is designed. Where the traffic is comparatively light and the subgrade is composed of some firm material which does not readily absorb water, a very satisfactory base may be constructed of broken stone. Where the traffic is comparatively heavy or where the material composing the subgrade is at all unstable, a monolithic concrete base should be used. Bases consisting of a course of brick laid flat upon a previously compacted layer of gravel or broken stone have sometimes been used, and pavements constructed upon bases of this kind, ordinarily called "double-layer" pavements, have in general proved satisfactory. At the present time, however, such bases can rarely be constructed at less cost than the more durable concrete bases, and they will therefore be given no further consideration here.

Broken-stone bases should be from 6 to 8 inches thick after compacting and should be constructed in two or more courses just as in

the case of first-class macadam roads. The materials used should conform in all respects to the ordinary requirements for similar materials used in constructing such roads; that is, the stone should be clean, hard, tough, and durable, and should be graded in size between certain reasonable, fixed limits. It should be uniformly spread on the road, either from dumping boards by means of shovels or from wagons especially designed to spread the material as it is being dumped. Where whole loads are dumped in one place and then spread out to the required depth, it is very difficult to obtain uniform density. Usually those spots where the loads are dumped are more densely compacted than the rest of the base, and this lack of uniformity very soon manifests itself by producing unevenness in the

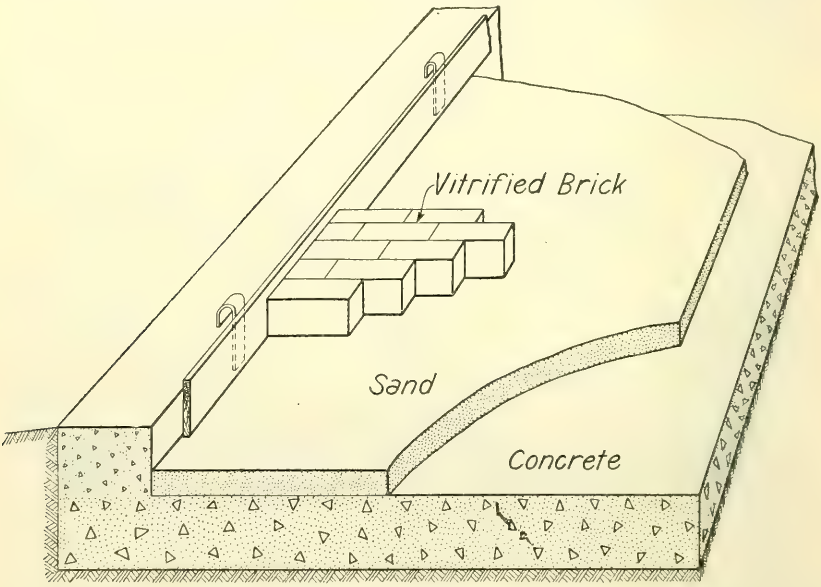


FIG. 3.—Making provision for expansion joint.

surface of the pavement. Broken stone should be compacted in the usual manner by rolling the base with a power roller weighing not less than about 10 tons, and sufficient clean stone chips to fill the voids should be spread and flushed into the base while the rolling is in progress. When complete the base should present a surface uniform in grade and cross section and parallel to the proposed surface of the finished pavement.

Concrete bases are unquestionably better adapted for brick pavements than any other type. They are practically monolithic in form, nearly impervious to water, and possess a relatively high crushing strength. All of these qualities may be obtained with a relatively "lean" concrete if the subgrade has been properly prepared. Under

ordinary circumstances a satisfactory base may be constructed of concrete composed of 1 part of Portland cement, 3 parts of sand, and from 5 to 7 parts of broken stone or screened gravel.

The sand should be clean and well graded in size, and the stone or gravel should conform to the usual requirements for coarse aggregate to be used in concrete construction.

Foundations for brick pavements have also been constructed of planks laid on sand, and in some instances of sand alone. These foundations have seldom proved satisfactory for any great length of time, and can, therefore, be economically used only when the pavement is to be constructed of an inferior grade of brick.

SAND CUSHION.

Since it is practically impossible to construct an absolutely smooth base, and since there is always a slight variation in the size of paving brick, owing to slight differences in the amount of shrinkage at the time of burning, it is necessary to provide an adjustable cushion of some kind between the base and the brick for correcting these slight irregularities, in order to secure an even surface and a uniform bearing for the brick. Sand has been found a most satisfactory material of which to construct this cushion, and is almost exclusively used for this purpose. The proper thickness for the sand cushion will of course depend on the extent of the inequalities above mentioned. Two inches is the most usual thickness, and has generally proved very satisfactory. One and one-half inches, however, is in many cases entirely sufficient.

The sand used in the cushion should be moderately clean and free from pebbles. If dirt or vegetable matter is present, it will soon be leached out and cause unevenness to develop in the pavement, while pebbles prevent the brick from securing a uniform bearing and ultimately produce the same result. It is also important that the sand should be dry when spread, especially if it is fine, because a comparatively small amount of moisture increases the volume of fine sand considerably, and moisture when present is not, as a rule, uniformly distributed. Even if it were uniformly distributed at the start, some spots would dry out more rapidly than others while the spreading was under way, and a lack of uniformity would thus be produced in the cushion.

In forming the cushion the sand is uniformly spread over the base to a depth slightly in excess of that desired, and is then smoothed off by drawing over it a template shaped to conform with the cross section of the finished pavement. The length of the template is ordinarily made equal to the width of the pavement where this is less than about 25 feet, and equal to half the width for wider pavements. Timber guides may be laid in the same direction as the pavement for

the template to slide on, or the curbs may be made to serve as guides where this is convenient.

After the cushion is spread and uniformly "struck off" with the template to a depth slightly in excess of that required, it should be thoroughly compacted by rolling with a hand roller weighing from 300 to 400 pounds, and any depressions which form should be corrected. This is necessary in order to secure uniform density and to prevent unequal settlement of the surface.

HANDLING AND LAYING THE BRICK.

The brick may all be hauled and piled at convenient intervals along the sides of the roadway before grading is begun, or, if more convenient, they may be delivered as needed on the work. Hauling over the finished pavement with wagons until it is complete and opened to traffic should be avoided. If the brick are delivered on the work as needed, they should be unloaded from the wagons outside of the curb and carried to the pavers, either by hand or in wheelbarrows. Plank trackways should also be provided over the newly laid pavement for the wheelbarrows when they are used.

The brick should in all cases be uniformly piled by hand on the new pavement conveniently close for the pavers, and each brick should be so placed that the regular operation of picking it up and placing it in the pavement will bring the best edge up. This method of handling the brick requires somewhat more labor than the common method of dumping them from wheelbarrows, but it eliminates to a great extent the practice of picking out and turning over chipped or kiln-marked brick after the pavement is laid. This is very objectionable on account of the disarrangement of the sand cushion, which is frequently occasioned.

The brick should be laid on edge and in uniform courses, running at right angles to the line of the pavement, except at intersections; and in order to "break the joints" each alternate course should begin with a half brick. In laying the brick the pavers stand on the pavement already laid and, beginning at the curb each time, carry across as many courses together as they can conveniently reach. The courses should be kept straight and close together, and, if necessary, each block of eight or ten courses may be driven back by means of a light sledge and a piece of straight timber approximately 2 by 4 inches by 5 or 6 feet long, though no heavy driving should be permitted. The brick should also be laid close together in the courses.

After the brick are laid the pavement should be carefully inspected, for the purpose of detecting soft or otherwise defective brick. Misshapen or broken brick may be detected by the eye alone, and the soft brick by sprinkling the pavement with water. The soft brick appear comparatively dry while the water is being applied and compara-

tively wet after the sprinkling is stopped. All defective brick should of course be replaced by others which meet the requirements of the specifications.

TRUING THE SURFACE.

After the pavement has been laid and all defective brick have been replaced to the satisfaction of the engineer, the next step is to sweep the surface clean, and smooth out all inequalities by means of ramming and rolling. The rolling should be done with a power roller weighing from 3 to 5 tons, and the pavement should ordinarily be rolled in both longitudinal and diagonal directions. The longitudinal rolling should be done first, and should begin at the curbs and progress toward the crown. The roller should pass at least twice over every part of the pavement in each direction. In order to neutralize any tendency which the brick may have to careen under the roller, the number of forward trips over any part of the pavement should equal the number of trips backward over the same part.

In places where it is impracticable to use the roller for truing the surface—such, for example, as along the curbs or concrete gutters or around manholes—the brick should be brought to a true surface by means of ramming. For this purpose a wooden rammer loaded with lead and weighing from 80 to 100 pounds may be used. The blows of the rammer should not fall directly upon the brick, but should be transmitted through a 2-inch board laid parallel to the curb.

After the pavement has been trued up, as described above, it should be inspected again for broken or otherwise damaged brick, and also for those which have settled excessively, owing to some lack of uniformity in the sand cushion. All defects should be corrected, and the areas disturbed in making the corrections should be brought to a true surface by tamping or rolling.

FILLING THE JOINTS.

In order to keep the brick in proper position and protect the edges from chipping it is necessary to fill the joints with some suitable material before the road is opened to traffic. The materials which have in the past been most commonly used for this purpose are sand, various bituminous preparations, and a grout made of equal parts of Portland cement and fine sand mixed with water.

Sand is the least expensive of these materials, but there are several very serious objections to its use as a joint filler: (1) It does not protect the edges of the brick; (2) it is easily disturbed in cleaning the pavement and is likely to be washed out by rain on steep

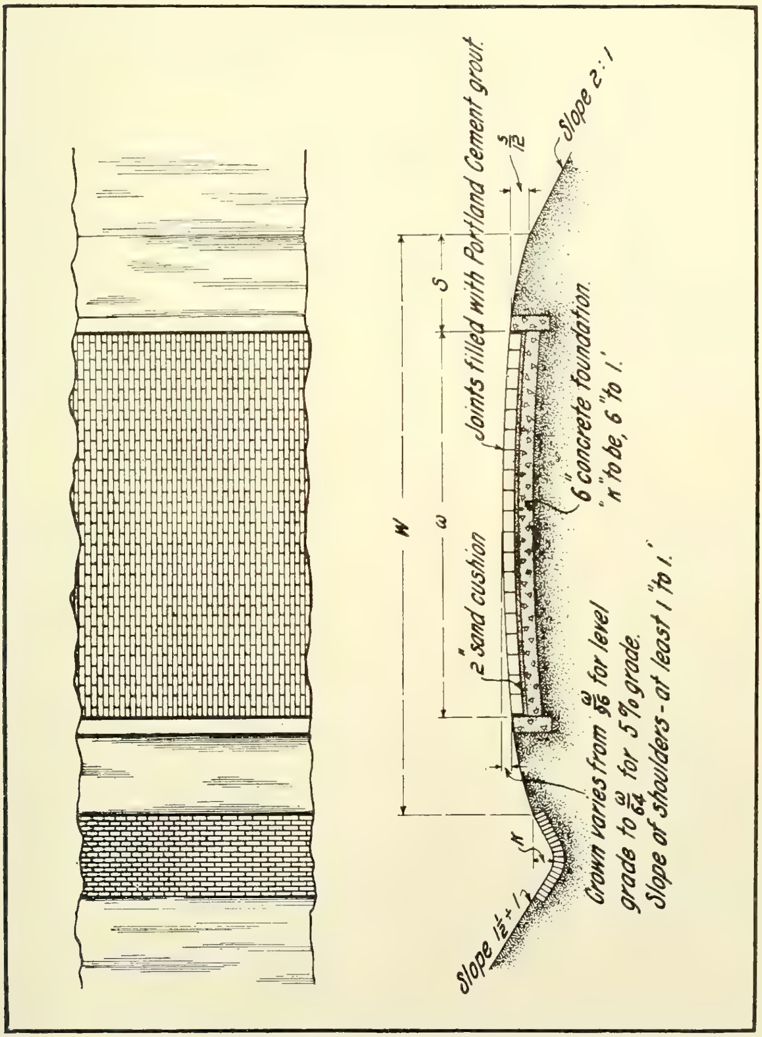
grades; (3) it does not entirely prevent water from penetrating through to the foundation; and (4) it does not bond the individual brick together and so enable them to present a concerted resistance to traffic.

The bituminous fillers vary considerably in quality and efficiency, but all are more or less unsatisfactory. One of the principal objections to their use is based on their tendency to run out of the joints into the gutters during warm weather and to crack and spall out during cold weather. This tendency can, of course, be partially overcome by exercising proper care in selecting the materials. It should also be noted in their favor that brick pavements, the joints of which have been filled with bituminous preparations, are ordinarily less noisy at first than those in which a Portland cement grout filler has been used. The grout filler is unquestionably very much superior from a standpoint of durability, however, and the excessive noise under traffic which has been frequently observed in connection with its use can be largely eliminated by the use of proper bituminous expansion cushions along the curbs. It is, therefore, recommended as better adapted for filling the joints in brick pavements than any other material which has been commonly used for that purpose.

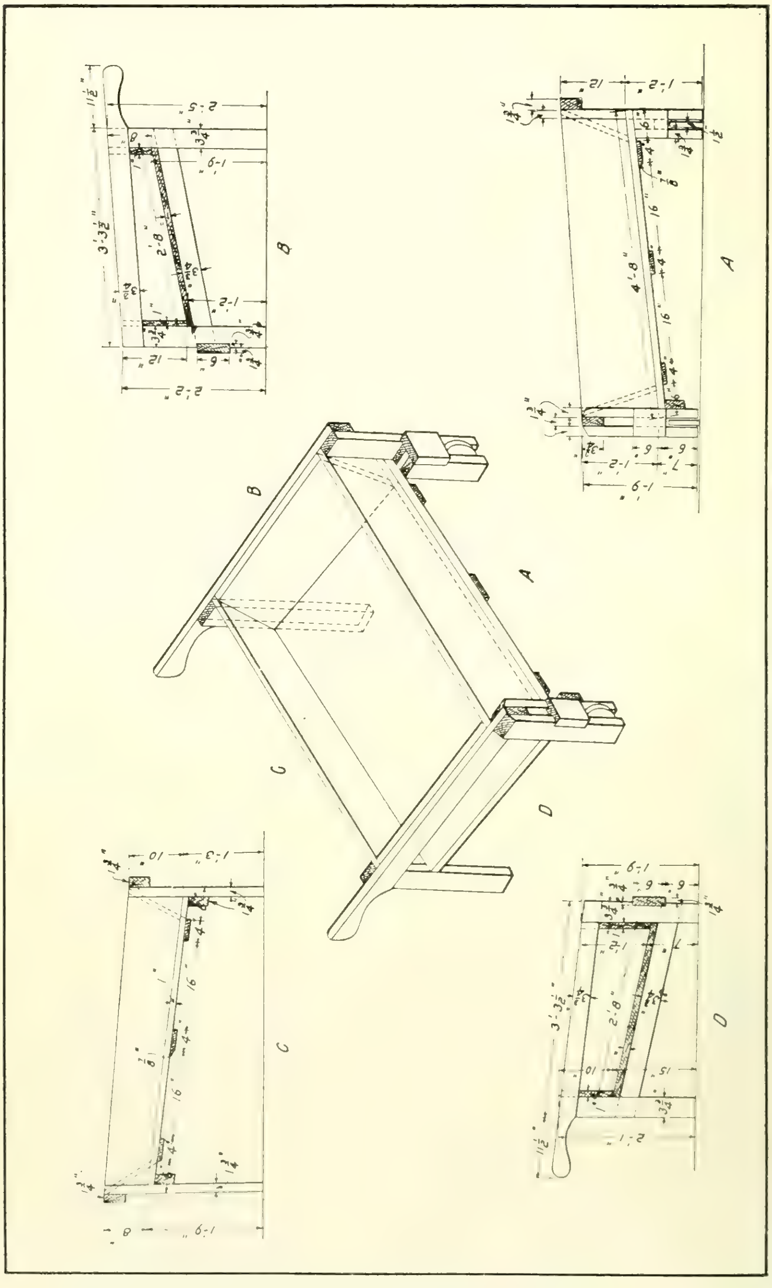
When the joints of a brick pavement are properly filled with Portland cement grout the individual brick are firmly bonded together and the pavement is thereby practically converted into a monolith. Moreover, since the material composing the joints scarcely wears more rapidly than the brick, the edges of the brick are well protected, and the importance of this feature has already been pointed out.

The most satisfactory method yet devised for mixing and applying the grout filler may be described as follows: Grout boxes, constructed in such manner that when resting on a level platform one corner will be lower than the others, should first be provided. A suitable design for such boxes is shown in Plate II. The number of boxes required depends on the width of the pavement; ordinarily one box to each 10 feet of width will be found sufficient. The grout, which should be put on in two applications, is prepared in batches each of which consists of a quantity of cement not exceeding one sack, a like amount of fine, clean sand, and water. The sand and cement should first be thoroughly mixed dry and sufficient water then added to produce a liquid mixture. The consistency of the mixture for the first application should be approximately the same as that of ordinary cream, and for the second application it should be somewhat thicker.

The pavement should be cleaned and thoroughly sprinkled as a preliminary to making the first application of grout, and it should



TYPICAL PLAN AND SECTION FOR BRICK ROAD.



PLAN FOR GROUT BOX HAVING LOW CORNER.

FIG. 1.—FINE GRADING.

FIG. 2.—ROLLING.

PREPARING THE SUBGRADE FOR A BRICK ROAD.

FIG. 1.—MIXING CONCRETE FOR THE BASE.

FIG. 2.—FINISHED CONCRETE BASE.

EXPERIMENTAL ROAD AT CHEVY CHASE, MD.

FIG. 1.—SPREADING SAND CUSHION.

FIG. 2.—ROLLING SAND CUSHION.

EXPERIMENTAL ROAD AT CHEVY CHASE, MD.

FIG. 1.—LAYING THE BRICK.

FIG. 2.—ROLLING THE PAVEMENT.

EXPERIMENTAL ROAD AT CHEVY CHASE, MD.

FIG. 1.—FILLING THE JOINTS, FIRST COAT.

FIG. 2.—FILLING THE JOINTS, SECOND COAT.

EXPERIMENTAL ROAD AT CHEVY CHASE, MD.

FIG. 1.—FINISHED BRICK PAVEMENT PROTECTED BY SAND COVERING.

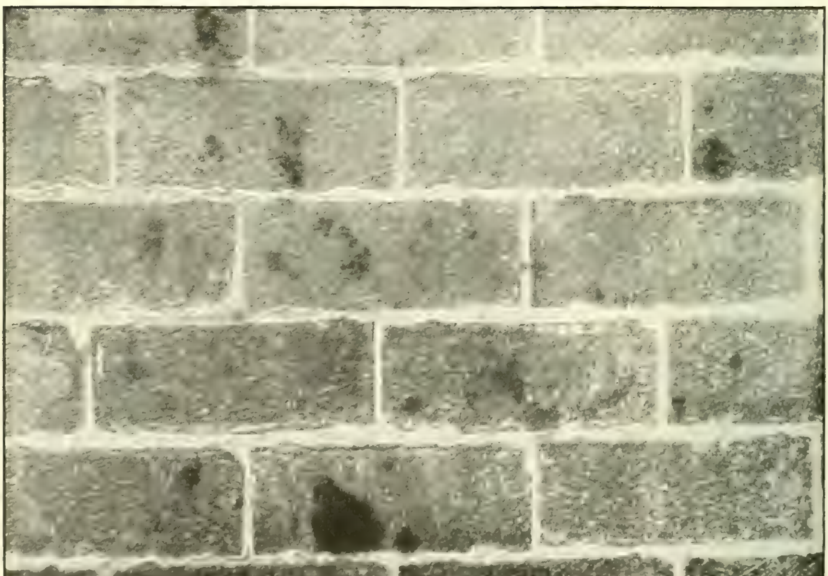


FIG. 2.—SHOWING PROPERLY FILLED GROUT JOINTS.

EXPERIMENTAL ROAD AT CHEVY CHASE, MD.

FIG. 1.—EXPERIMENTAL ROAD AT CHEVY CHASE, MD.

Finished pavement in service.

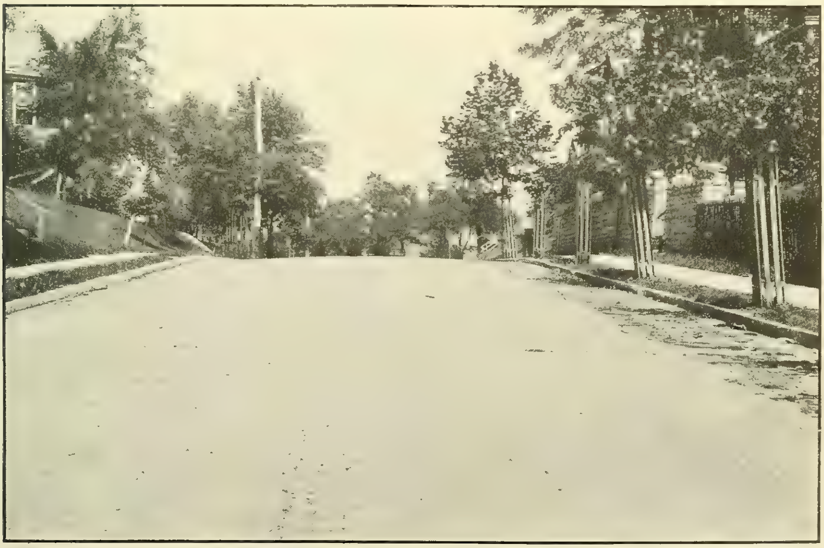
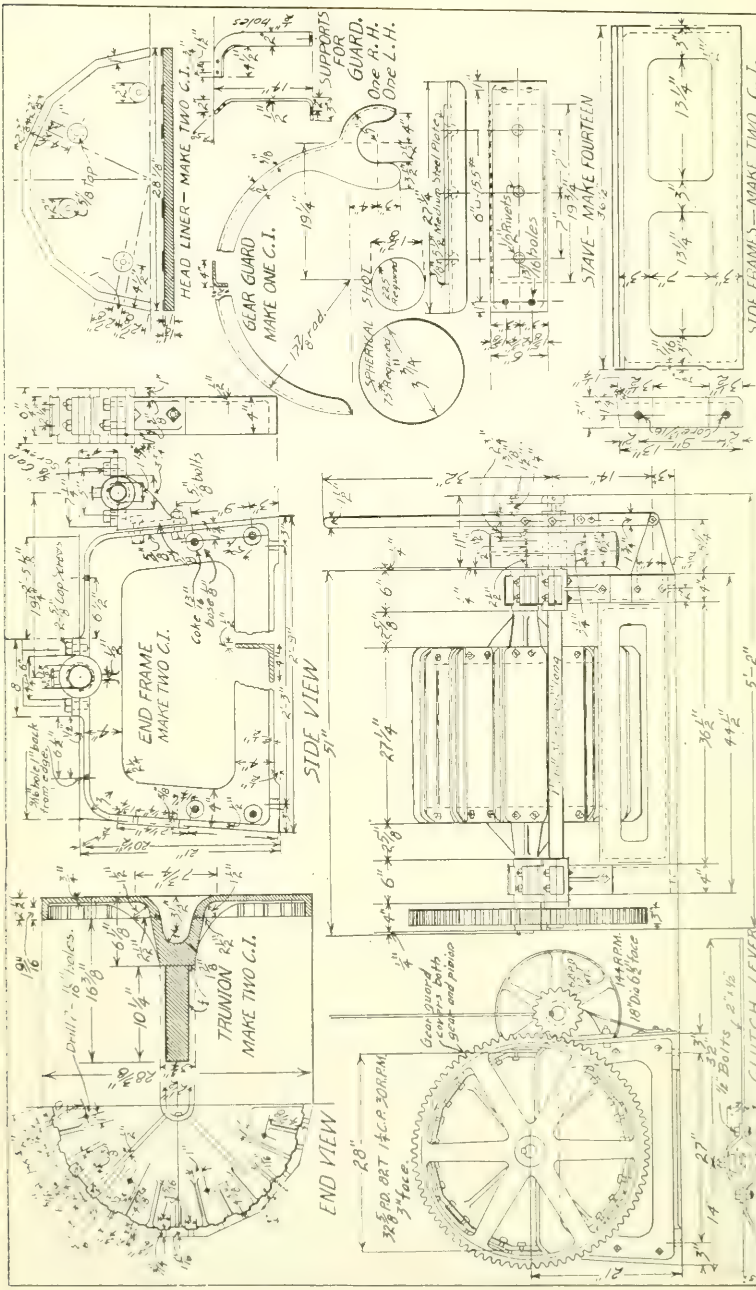


FIG. 2.—GROUT-FILLED BRICK PAVEMENT, HAVING LONGITUDINAL JOINTS IN CENTER AND OCCASIONAL TRANSVERSE JOINTS FILLED WITH SOFT FILLER.

Unsightly appearance at right caused by widening roadway.



PLAN FOR RATTLER.

be kept moist by gentle sprinkling while this application is being made. The grout should be swept into the joints immediately after it is removed from the boxes and spread upon the pavement. For this purpose a coarse rattan or fiber push broom should be used in the first application and a squeegee in the second application. The squeegee is usually made by clamping a piece of four-ply rubber belting or some other similar material, about 6 by 20 inches in size, between two pieces of board and attaching a suitable handle. The grout in the boxes should be continually stirred until the last of it is removed, otherwise a separation of the sand and cement will almost certainly occur.

The first application should proceed about 50 feet in advance of the second. Usually both applications are made by the same crew of laborers. They simply turn back after having covered the allowable distance with the first application and, mixing the grout in the same boxes, bring up the second application. The second application of grout should completely fill the joints flush with the top of the brick.

After the joints are filled as described above and the grout has taken its initial set, the entire surface should be covered to a depth of approximately 1 inch with sand or fine earth. This is done to protect the pavement from the weather and to keep it in a moist condition while the grout is hardening. If necessary, in order to keep the covering moist, it should be occasionally sprinkled for several days after it is spread.

The covering should be permitted to remain on the surface for at least 10 days, and during this period the pavement should be kept entirely closed to traffic. If the weather is unfavorable, the length of time during which traffic is kept off the road should be increased.

EXPANSION CUSHIONS.

It has been customary in the past to provide both longitudinal and transverse bituminous expansion cushions in grout-filled brick pavements, but recent practice has demonstrated that the transverse cushions may be advantageously omitted if proper longitudinal cushions are provided. The principal objection to the use of transverse expansion cushions is based on the fact that the material composing the cushions frequently softens during warm weather and runs out toward the curb, thus leaving the edges of the adjoining brick exposed to destructive impact from the wheels of passing vehicles. Even if the cushion consists of a material which does not run in warm weather, it is necessarily softer than the brick, and the natural result is still the development of unevenness in its immediate vicinity. No such objection can exist concerning longitudinal expansion cushions, however, if they are placed adjacent to the curbs

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and constructed of proper material. They not only furnish a means for the pavement to expand and contract with changes in temperature, but they also eliminate to a large extent the disagreeable rumbling which has been so frequently associated with grout-filled brick pavements.

The bituminous material of which the expansion cushions are made should be such as to remain firm in summer and not to become brittle in winter. It should also possess the quality of durability. In order to insure that any given material is suited for such a purpose, it is usually considered necessary to prescribe certain laboratory requirements to which it must conform, and examples of these, which have been found to give good results, are contained in the section entitled "Typical specifications." (Cf. p. 22 et seq.)

Expansion cushions should be provided for at the time the brick are laid, by placing a board of the required thickness on edge adjacent to each curb, as shown in figure 3. Small iron wedges, such as are shown in this figure, may be inserted between the curb and the board at the time the board is set. These wedges may be readily loosened and removed after the bricks have been laid and grouted, and may consequently be made to facilitate the removal of the board.

The proper thickness for expansion cushions is a matter concerning which much difference of opinion exists among highway engineers. Some engineers advocate a minimum thickness of 1 inch, while others claim to have secured their best results by using expansion cushions having a minimum thickness as low as three-eighths inch for very narrow pavements. It is generally agreed that the thickness of the cushion should vary with the width of the pavement. The following suggestions for proportioning the cushion are offered as being fairly representative of the best practice:

TABLE 1.—*Ratio of thickness of cushions to width of roadway.*

Width of roadway (feet).	Thickness of cushion (inches).
20 or less	$\frac{1}{2}$
20 to 30	$\frac{3}{4}$
30 to 40	1
Over 40	$1\frac{1}{4}$

Plates III to VII, and Plate VIII, figure 1, show the various steps in the construction of a brick pavement. Plate VIII, figure 2, and Plate IX, figure 1, show the finished pavement as it should appear, and Plate IX, figure 2, shows the advantage possessed by grout-filled joints over joints filled with a soft material.

COST OF BRICK PAVEMENTS.

The cost of brick pavements varies widely and is affected by so many influences that it is difficult to attempt to derive a general expression showing the relation between probable cost and local conditions. The prices of brick, as also the prices of the various materials entering into the foundation, vary greatly according to the locality and the freight rate. The cost and efficiency of labor is also far from being constant. Furthermore, the material composing the subgrade and the method of preparing it may exert a marked influence on the cost of the pavement. The following statements regarding cost, then, must be considered as representing average conditions, and care must be exercised in applying them to special cases. They are intended as a guide in preparing estimates of probable cost.

The grading is usually paid for by the cubic yard, and the cost, of course, varies with the character of the soil and the necessary amount of excavation. In light, easily loosened soils, grading may usually be done at from 25 to 40 cents per cubic yard. In hard earth containing more or less loose rock the cost per cubic yard generally runs from 40 to 75 cents, while grading in solid rock may sometimes cost as much as $1.50 per cubic yard. The cost of the rough grading should be considered entirely apart from the cost of the pavement.

The cost of shaping and rolling the subgrade after the rough grading is completed will ordinarily vary from 3 to 5 cents per square yard. This cost should be included with the other items which make up the cost of the pavement.

The cost of the curbs varies with the character of the material used. Stone curbs ordinarily cost from 25 to 75 cents per linear foot, while curbs made of Portland cement concrete cost, as a rule, from 20 to 50 cents per linear foot. The higher prices for the concrete curbs apply principally to special cases requiring extra form work or considerable extra material.

The cost of the foundation depends largely on the cost of the materials with which it is constructed. Gravel or broken stone can usually be spread and rolled at from 5 to 7 cents per square yard, while the cost of these materials, delivered, varies from $0.60 to $2 per cubic yard. Mixing and placing concrete usually costs from 35 to 75 cents per cubic yard, according to the amount of work to be done and the methods employed, and the cost of the materials, delivered, ordinarily varies from $2.50 to $4.50 per cubic yard of concrete.

The cost of paving brick at the kiln varies from about $13 to $16 per thousand. Estimating 40 brick to the square yard, each 1,000 brick cover approximately 25 square yards, which makes the cost at the kiln per square yard of pavement vary from 55 cents to about 65

cents. These figures mean very little, unless the kiln is located conveniently near where the brick are to be used, for freight charges not infrequently amount to more than the cost of the brick.

A force consisting of one paver and five laborers should place on an average about 220 square yards of brick per 10-hour day; while supervision, rolling, and incidental expenses are ordinarily equivalent to the cost of hiring about three and one-half additional laborers.

If C = cost of cement per barrel, S = cost of sand per cubic yard, A = cost of coarse aggregate per cubic yard, B = cost of paving bricks per 1,000, and L = cost of labor per hour, with all materials considered delivered on the work and all costs expressed in cents, then the probable cost of constructing a brick pavement, including the subgrade, a 6-inch concrete foundation, and suitable curbs, may be estimated by substituting in the formula:

$$\text{Cost per square yard} = 1.90\ L + .213\ C + .138\ S + .157\ A + .040\ B.$$

The cost as estimated from this formula should usually be increased by about 10 per cent to allow for wear on tools and machinery and to guard against unforeseen contingencies. If it is desired to use a different thickness of foundation, it is safe to assume that each inch subtracted or added to the thickness of the foundation will make a corresponding difference of from 8 to 12 cents in the cost per square yard.

MAINTENANCE OF BRICK PAVEMENTS.

If brick pavements are properly constructed at the start, the work of maintaining them is very slight. Under the closest inspection, however, some inferior material is likely to become incorporated either in the foundation or in the surface, and it is therefore very important that a brick pavement be very carefully watched for the first few years of its life to see that no unevenness develops either because of defective brick having been used in the surface or because of insufficient support from the foundation at any point. Whenever any unevenness develops, it should be immediately rectified. Otherwise the pavement will become irregularly worn in the vicinity of the defects, and expensive repairs will eventually be necessary.

Not infrequently weak spots develop in broken stone or gravel foundations, owing to surface water finding its way through joints in the pavement which have not been properly filled with grout. Careful observation of the joints should therefore constitute a part of the early maintenance work, and any defective joints discovered should be immediately remedied. Where the foundation is constructed of concrete, however, slight defects in the joints seldom result in any very serious damage.

If care is exercised to correct all defects which appear within the first few years of the life of a well-constructed brick pavement, the work of maintaining the pavement proper should thereafter, except for cleaning, be almost negligible for a considerable period. The shoulders and drainage structures, of course, need occasional attention, just as in the case of any other pavement, but if they are properly constructed at the start repairs will usually be very slight.

The life of a well-constructed brick pavement can not be estimated with any great degree of exactness, first, because the traffic conditions are constantly changing, and, second, because no brick pavement which has been constructed in accordance with the best modern practice has yet worn out. Such measurements as have been made of the amounts of wear sustained by given pavements during comparatively long periods of years have not been sufficient to warrant any very definite conclusions as to the probable terms of service, though they indicate that good paving brick wear very slowly under ordinary traffic. It is evident that in order to secure the full benefit of this excellent resistance to wear the surface of the pavement must not be permitted to become uneven because of the failure of a brick here and there.

CONCLUSION.

Before concluding this discussion of brick pavements, it would seem desirable to emphasize the importance of proper engineering supervision. In the past many communities have expended large sums in efforts to improve their public highways without first having secured the services of some one competent to plan and direct the work. The results have usually been very unsatisfactory under such circumstances and have frequently served to discourage further effort. One of the mistakes most commonly observed consists in constructing some expensive type of pavement on a road where the location is faulty or the grades are impracticable. Not infrequently sharp angles in the alignment or abrupt changes in the grade, which might be easily and inexpensively remedied by an experienced engineer, are left to impede traffic throughout the life of a costly and perhaps durable pavement.

Even in constructing common earth roads it is doubtful economy to dispense with the services of a competent engineer, and if any considerable quantity of work is to be done, such services should certainly be secured. Since brick pavements are probably more expensive to construct than any other type of pavement at present used for country roads, it is all the more important that their construction should be carefully planned and well executed.

APPENDIX A.

Typical Specifications for Constructing Brick Roads.

SPECIFICATIONS[1] FOR GRADING AND SURFACING WITH BRICK THE ______________ ROAD.

Location.—The work referred to in these specifications is to be done on the ____________________ road, beginning at ________________ and extending in a __________ direction through ____________________ to ____________________, a distance of ______ miles.

Work to be done.—The contractor shall do all clearing and grubbing, make all excavations and embankments, do all shaping and surfacing, (construct all drainage structures and other appertaining structures),[2] move all obstructions in the line of the work, and, unless otherwise provided in these specifications, shall furnish all equipment, materials, and labor for the same. In short, the contractor shall construct said road in strict accordance with the plans and specifications and shall leave the work in a neat and finished condition.

PLANS AND DRAWINGS.

The plans, profiles, cross sections, and drawings on file in the office of ____________________ at ____________________ show the location, profile, details, and dimensions of the work which is to be done. The work shall be constructed according to the above-mentioned plans, profiles, cross sections, and drawings, which shall be recognized as a part of these specifications. Any variation therefrom which may be required by the exigencies of construction will in all cases be determined by the engineer. On all drawings, figured dimensions are to govern in cases of discrepancies between scale and figures.

GRADING.

Grading shall include the moving of all earth, stone, and any other material that may be encountered, all filling, borrowing, trimming, picking down, shaping, sloping, and all other work that may be necessary to bring the road and subgrade to the required grade, alignment, and cross section, the clearing out of waterways and old culverts, the excavation of all necessary drainage and outlet ditches, the grading of a proper connection with all intersecting highways, the grubbing up and clearing away of all trees, stumps, and boulders within the lines of the improvement, and the removal of any muck, soft clay, or spongy material which will not compact under the roller, so as to make a firm, unyielding subgrade.

All trees, stumps, and roots within the limit of the improvement shall be grubbed up so that no part of them shall be within six (6) inches of the surface of the ground or within eighteen (18) inches of the surface of the subgrade.

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[1] These specifications are substantially those prepared in the fall of 1913 by the Office of Public Roads for a project of considerable magnitude.

[2] The clause in parentheses should be omitted if plans and specifications for drainage structures are not included.

Embankments shall be formed of good, sound earth and carried up full width. The earth shall be deposited in layers not more than one (1) foot in thickness, and each layer shall be rolled until thoroughly compacted with a roller weighing not less than ten (10) tons. All existing slopes and surfaces of embankments shall be plowed or scarified where additional fill is to be made, in order that the old and new material may bond together. When sufficient material is not available within the fence lines to complete the embankments, suitable borrow pits, from which the contractor must obtain the necessary material, will be designated by the engineer. If there is more material taken from the cuts than is required to construct the embankments as shown on the plans, the excess material shall be used in uniformly widening the embankments or shall be deposited where the engineer may direct. Where embankments are formed of stone the material shall be carefully placed, so that all large stones shall be well distributed and the interstices shall be completely filled with smaller stone, earth, sand, or gravel, so as to form a solid embankment.

During the work of grading, the sides of the road shall be kept lower than the center and the surface maintained in condition for adequate drainage.

The grading of any portion of the road shall be complete before any surfacing material is placed on that portion; and where the plans do not call for any substantial change in the grade of any existing section of the road the surface shall be completely scarified to a depth of three (3) inches or more before the subgrade is prepared.

SUBGRADE.

The subgrade, or that portion of the road upon which the base for the brick roadway is to be laid, shall consist of good, sound earth brought to the proper elevation, alignment, and cross section, and shall be rolled until firm and hard. The rolling shall be done with a roller of the macadam type, weighing not less than ten (10) tons and not more than fifteen (15) tons. Should earth be encountered which will not compact by rolling, so as to be firm and hard, it shall be removed and suitable material put in its place, and that portion of the subgrade shall be again rolled. When the rolling is completed the surface of the subgrade shall conform to the cross section shown on the plans, and shall have the proper elevation and alignment, and shall be so maintained until the concrete base is in place.

MATERIALS.

Cement.—The cement for use in this work shall meet the requirements of the United States Government specifications for Portland cement as published in Circular No. 33, United States Bureau of Standards, issued May 1, 1912.

All cement shall be held at least ten (10) days after sampling before it is used in any part of the work. If the cement satisfactorily passes all tests that may be made within that time, it may be used and the twenty-eight (28) day test will not be insisted upon; but if it should fail to pass satisfactorily any test made within that time, then the cement shall not be used until it has satisfactorily passed all tests, including the twenty-eight (28) day test. All cement shall be delivered on the work in cloth or paper bags, containing ninety-four (94) pounds, net weight, and this amount of cement shall be considered as having a volume of one (1) cubic foot. In order to allow ample time for inspecting and testing, the cement shall be stored in a suitable weather-tight building, having the floor blocked or raised from the ground, and shall be so stored as to permit of easy access for inspection, and so that each carload shipment may be readily identified.

Sand.—The sand for use as fine aggregate in all concrete shall be composed of particles of hard, durable stone and not more than three (3) per cent, by weight, of clay or silt. No clay, however, will be permitted if it occurs as a coating on the sand grains. The grains shall be of such sizes that all will pass a one-fourth (¼) inch mesh screen, that not more than twenty (20) per cent will pass a No. 50 sieve, and that not more than sixty (60) per cent nor less than twenty (20) per cent will be retained on a No. 20 sieve. The sand shall be of such quality that a mortar made in the proportion of one (1) part of cement to three (3) parts of the sand, according to standard methods, when tested at any age not exceeding twenty-eight (28) days, will have a tensile strength of at least one hundred (100) per cent of that developed in mortar of the same proportions made of the same cement and standard Ottawa sand. The cement used in these tests shall be from an accepted shipment of that proposed for use with the sand.

The sand for the sand cushion shall be composed of particles of hard, durable stone and not more than five (5) per cent, by weight, of clay, loam, or silt. The sizes of the grains shall be such that all will pass a one-fourth (¼) inch mesh screen and not more than fifty (50) per cent will pass a No. 30 sieve. Stone screenings will not be accepted for use in the sand cushion.

The sand for the grout filler shall be composed of quartz grains and not more than one (1) per cent, by weight, of clay or silt. The grains shall be of such size that all will pass a No. 20 sieve and that not more than forty (40) per cent will pass a No. 50 sieve. The sand shall be of such quality that a mortar made in the proportion of one (1) part of cement to three (3) parts of the sand, according to standard methods, when tested at any age not exceeding twenty-eight (28) days, will have a tensile strength of not less than seventy-five (75) per cent of that developed in mortar of the same proportions made of the same cement and standard Ottawa sand. The cement used in these tests shall be from an accepted shipment of that proposed for use with the sand.

Gravel.—The gravel for use in the concrete base shall be composed of hard, sound, durable particles of stone and not more than three (3) per cent, by weight, of clay or silt. No clay, however, will be permitted if it occurs as a coating on the particles of stone or as lumps more than one (1) inch in diameter. The particles of stone shall be graded in size between those retained on a screen having circular openings one-fourth (¼) inch in diameter, or a one fourth (¼) inch mesh screen, and those passing a screen having circular openings two (2) inches in diameter. Not more than seventy-five (75) per cent of the particles shall pass and not more than seventy-five (75) per cent shall be retained on a screen having circular openings three-fourths (¾) inch in diameter.

The gravel for use in the concrete curbs shall be composed of hard, sound, durable particles of stone, thoroughly clean and graded in size between those retained on a screen having circular openings one-fourth (¼) inch in diameter, or a one-fourth (¼) inch mesh screen, and those passing a screen having circular openings one (1) inch in diameter. Not less than forty (40) per cent shall be retained on and not less than twenty (20) per cent shall pass a one-half (½) inch mesh screen.

Crushed stone.—The crushed stone for use in the concrete base shall be clean, sound, and durable, and shall be composed of all that part of the product of the crusher which is retained on a screen having circular openings one-fourth (¼) inch in diameter, or a one-fourth (¼) inch mesh screen, and which passes a screen having circular openings two (2) inches in diameter. A sample of the stone, when subjected to the physical tests as described in the United States

Office of Public Roads Bulletin No. 44, shall satisfactorily meet the following requirements:

Hardness not less than ten (10), toughness not less than five (5), and per cent of wear not more than twelve (12).[1]

The crushed stone for use in the concrete curb shall be clean, sound, and durable, and shall be composed of all that part of the product of the crusher which is retained on a screen having circular openings one-fourth (¼) inch in diameter, or a one-fourth (¼) inch mesh screen, and which passes a screen having circular openings one and one-fourth (1¼) inches in diameter. A sample of the stone, when subjected to the physical tests as described in the United States Office of Public Roads Bulletin No. 44, shall satisfactorily meet the following requirements:

Hardness not less than twelve (12), toughness not less than six (6), and per cent of wear not more than ten (10).[1]

Slag.—The slag for use in the concrete base shall be steel-furnace slag, broken to such sizes that all of the particles will pass a screen having circular openings two (2) inches in diameter and will be retained on a screen having circular openings one-fourth (¼) inch in diameter, or a one-fourth (¼) inch mesh screen. Not more than seventy-five (75) per cent of the particles shall pass and not more than seventy-five (75) per cent shall be retained on a screen having circular openings three-fourths (¾) inch in diameter.

The material shall be reasonably uniform in character, and a sample, when subjected to the physical tests, as described in United States Office of Public Roads Bulletin No. 44, shall satisfactorily meet the following requirements:

Specific gravity not less than two and one-tenth (2.1), hardness not less than fifteen (15), toughness not less than five (5), and per cent of wear not more than fifteen (15).

A sample of the slag proposed to be used, weighing not less than one hundred (100) pounds, shall be furnished to the engineer by the contractor at least thirty (30) days before it is proposed to use the slag in the work. Test specimens of concrete, composed of one (1) part of cement, two and one-half (2½) parts of sand, and five (5) parts of the slag, may be made, and they shall have a compressive strength, when tested at any age not exceeding twenty-eight (28) days, equal to that of a concrete composed of one (1) part of cement, two and one-half (2½) parts of sand, and five (5) parts of crushed stone of the quality herein specified for the concrete base.

Water.—The water used in the mixing of concrete or grout shall be free from oil, acid, alkali, or vegetable matter, and fairly free from clay or silt.

Brick.—The brick shall be standard wire-cut lug or re-pressed paving block. The standard size of brick shall be three and one-half (3½) inches in width, four (4) inches in depth, and eight and one-half (8½) inches in length. The brick shall not vary from these dimensions more than one-eighth (⅛) inch in width and depth and not more than one-half (½) inch in length, and in brick of the same shipment the maximum width or depth shall not vary from the minimum width or depth more than one-eighth (⅛) inch. All brick must be thoroughly annealed, regular in size and shape, and evenly burned. When broken they shall show a dense, stonelike body, free from lime, air pockets, cracks, and pronounced laminations. No surface of any brick shall have kiln marks more than three-sixteenths (3/16) inch in depth or cracks more than three-eighths (⅜) inch in depth, and the wearing surface of the brick shall not have

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[1] The values given for hardness, toughness, and per cent of wear are intended to exclude unsatisfactory stone, but in communities where better stone is readily available the requirements should be made more rigid.

kiln marks more than one-sixteenth ($\frac{1}{16}$) inch in depth and shall be free from cracks. The brick shall have not less than four (4) and not more than six (6) lugs, all on one side of the brick, such that when the brick are properly laid in place in the pavement the joints between them will be not less than one-eighth ($\frac{1}{8}$) nor more than one-fourth ($\frac{1}{4}$) inch in width. The name or trade-mark of the manufacturer, if shown on the brick, must be recessed and not raised. If the edges of the brick are rounded, the radius shall not exceed one-eighth ($\frac{1}{8}$) inch.

The brick must not be chipped in such a manner that the wearing surface is not intact or that the lower or bearing surface is reduced in area more than ten (10) per cent; but chipped brick, if otherwise satisfactory, may be used in obtaining the half brick for breaking courses and the necessary pieces of brick for closures. The brick shall not be salt glazed or otherwise artificially glazed. Not less than five (5) samples of ten (10) brick each will be selected from each kiln or shipment and subjected to the rattler test recommended to the American Society for Testing Materials by its subcommittee on paving brick; one sample from what appears to be the softest brick, which shall not lose of its weight more than twenty-four (24) per cent; one sample from what appears to be the hardest brick, which shall not lose of its weight less than sixteen (16) per cent or more than twenty-four (24) per cent; and three samples representing an average of the kiln or shipment, which shall not lose of their weight more than twenty-two (22) per cent: *Provided, however*, That if the softest brick lose less than twenty-four (24) per cent, the permissible minimum loss of the hardest brick will be reduced a like amount. If the kiln or shipment of brick should fail to meet the above requirements—and it is fair to assume that it would meet them if not more than ten (10) per cent were culled—then the contractor may, at his option, regrade the brick. When the regrading is complete the kiln or shipment will be resampled and retested as under the original conditions, and if it fails to meet any of the above requirements it will be finally and definitely rejected. Sampling will be done at the factory prior to shipment or from cars when placed on siding at destination, and brick satisfactorily passing the rattler test will not be rejected as a whole, but will be subject to such culling as may be necessary to meet all of the above requirements. The brick shall be carefully unloaded from cars and wagons by hand and neatly piled along the work in such manner that they will be clean and in proper condition to be laid in the pavement when desired.

Bituminous filler for expansion cushion.—The bituminous filler for the expansion cushion between the brick pavement and the curb shall be a blown-oil asphalt. It shall be soluble in chemically pure carbon disulphide to at least ninety-nine (99) per cent, and when tested by the cube method, as described in United States Office of Public Roads Bulletin No. 38, its melting point shall not be less than ninety (90) degrees centigrade and not more than one hundred and ten (110) degrees centigrade. The penetration at zero (0) degrees centigrade of a No. 2 needle acting one (1) minute under a weight of two hundred (200) grams shall be not less than two (2) millimeters. The penetration at forty-six (46) degrees centigrade of a No. 2 needle acting five (5) seconds under a weight of fifty (50) grams shall not exceed ten (10) millimeters.

CONSTRUCTION.

Concrete base.—Upon the subgrade prepared as herein specified shall be laid a concrete base of the width and thickness shown on the plans. The subgrade shall be wet but not muddy when the concrete is placed upon it. The concrete shall be composed of the following materials, by volume: One (1) part of cement, three (3) parts of sand, and five (5) parts of gravel, crushed stone, or crushed

slag, and sufficient water to form a quaky mass, and shall be thoroughly mixed in a machine mixer of the batch type so constructed and operated that the thorough mixing of the materials will be assured. The concrete shall be so delivered to its place on the subgrade as not to cause or permit any separation of the materials. Wheelbarrows or other devices used for measuring the materials shall be of uniform capacity. The concrete shall be deposited in place immediately after it is mixed and shall be well compacted as fast as it is placed. The top surface shall be smoothed by troweling with shovels or by some other means approved by the engineer, and when completed shall not vary more than one-half (½) inch from the proper shape and grade, as shown on the plans and profiles. The concrete base shall be kept wet by sprinkling with water during the first four (4) days after it is laid. No hauling over it or rolling or tamping of brick upon it will be permitted for seven (7) days after it is placed, and during this time it shall be properly protected from injury. Concrete shall not be mixed when the temperature of any of the materials is less than thirty-five (35) degrees Fahrenheit. Concrete shall not be used after it has begun to show evidence of setting, and no concrete which has once set shall be used as material for mixing a new batch.

Curbs.—Concrete curbs shall be built on the base as shown on the plans. The concrete shall be composed of the following materials, by volume: One (1) part of cement, one and one-half (1½) parts of sand, three (3) parts of gravel or crushed stone, and water. The materials shall be thoroughly mixed in a machine mixer of the batch type or by hand. If the mixing is done by hand, it shall be done upon a water-tight platform with raised edges, in the following manner: The sand and cement shall be thoroughly mixed dry and spread out upon the mixing platform, and upon this dry mixture shall be spread the coarse aggregate. Water shall then be poured over the aggregate in such an amount that the resultant concrete will be of a quaky consistency. The whole mass shall then be turned with shovels until all of the materials are thoroughly mixed. The concrete for the curb shall be placed upon the base before the concrete of either the curb or the base has taken its initial set, and care shall be taken, such as roughening the concrete of the base and tamping the concrete of the curb, to insure that the curb will be firmly bonded to the base. The concrete shall be well tamped and spaded along the forms, so that when they are removed there will be no open and porous places on the sides of the curb. The top surface of the curb shall be floated or troweled to a smooth finish. The forms for the curb shall be smooth, clean, free from warp, and of sufficient strength to resist springing out of shape. They shall be well staked and braced, and the top edges shall be at the same height and set true to line. To protect the curb from drying out too rapidly it shall, within twelve (12) hours after it is placed, be covered with gunny cloth, which shall be kept wet for five (5) days.

Sand cushion.—Upon the base shall be spread a cushion of sand such that it will have a uniform depth of two (2)[1] inches when compacted. The base shall be thoroughly clean at the time the sand is spread. The cushion shall be carefully shaped to a true cross section of the roadway by means of a template having a steel-faced edge, and so fitted as to be readily drawn on the curb. After the cushion is so shaped it shall be rolled with a hand roller until the sand is well compacted. The depressions formed by rolling shall be filled and the surface of the cushion trued up with the template and rolled again. This operation of filling depressions, truing up with template, and rolling shall be repeated as often as is necessary to secure a well-compacted cushion true to

[1]A sand cushion having a uniform depth of 1½ inches is frequently used and may be as satisfactory as the 2-inch cushion.

grade and to the required cross section. The rolling shall be done with a hand roller not less than twenty-four (24) inches in diameter, not less than twenty-four (24) inches in width, and weighing not less than ten (10) pounds per inch in width.

Laying brick.—Upon the sand cushion, prepared as above described, the brick shall be laid on edge from curb to curb in straight courses at right angles to the curb, with the lug sides all in the same direction. The brick shall be laid so that the lugs of the brick in one course will touch the brick in the adjoining course, and the joints between the ends of the brick shall not exceed one-eighth ($\frac{1}{8}$) inch in width. Joints shall be broken by starting each alternate course with a half brick. Nothing but whole brick shall be used, excepting the half brick for starting alternate courses and pieces of brick for closures, and no piece of brick less than two (2) inches in length shall be used for making a closure. The cutting and trimming of brick shall be done by experienced men, and proper care shall be taken not to check or fracture the part to be used, and the ends of the part used shall be square with its top and sides.

The brick shall be carried to the bricklayers on pallets or in clamps and not wheeled in barrows. The bricklayers laying the brick shall stand on the brick already laid and shall not in any manner disturb the sand cushion. No heavy driving will be permitted to straighten courses, and in making closures the pieces of brick shall be so cut that they may be laid in place without driving. Brick shall be laid with the best edge up. Batting for closures shall progress with the laying.

After the brick are laid they will be carefully inspected, and all those which are soft, cracked, glazed, spalled, overburned, or otherwise imperfect will be marked by the inspector. The contractor shall at once remove such brick from the pavement with flat-nosed tongs, without disturbing the sand cushion, and shall replace them with approved brick. Kiln-marked and slightly chipped brick, if not otherwise defective, may be turned over and, if the reverse edge is smooth, may remain in the pavement.

If more than one kind of brick or the brick from more than one plant is furnished for the work, each particular kind or make shall be laid in a separate section.

Rolling brick.—After the brick have been laid and after all objectionable brick have been removed from the pavement they shall be brought to a true surface and thoroughly bedded on the sand cushion by means of rolling. The rolling shall be done with a motor or steam tandem roller weighing not less than three (3) and not more than five (5) tons. The pavement shall be rolled in longitudinal and diagonal directions. The longitudinal rolling shall begin at the curbs and progress toward the center of the pavement, and shall be continued until the brick are well bedded on the sand cushion. The pavement shall then be thoroughly rolled diagonally at an angle of forty-five (45) degrees with the curb. When this rolling has been completed the brick will again be inspected, and all that are broken or damaged shall be removed from the pavement and replaced with approved brick. The brick shall then be again rolled, the roller moving diagonally across the pavement at right angles to the first diagonal rolling. To prevent the brick from being left careened the roller shall in all cases cover exactly the same area in making its backward trip as was covered in its forward trip, and shall proceed at a very slow rate of speed until the entire pavement has received the first rolling. In no event shall the rolling be done when the sand cushion is in a condition such that the sand will flow up into the joints more than three-eights ($\frac{3}{8}$) inch.

Filling the joints.—After the brick have been rolled as above specified the joints between them shall be filled with a grout containing equal parts of cement

and sand. The grout shall be mixed in batches containing not more than one sack of cement in a box about five (5) feet long, thirty (30) inches wide, and fourteen (14) inches deep, resting on legs of different lengths, so that the mixture will readily flow to the lowest corner of the box. The sand and cement shall be thoroughly mixed dry. Sufficient clean water shall then be admixed to produce a grout of a consistency about equal to that of ordinary cream for the first application and of a slightly thicker consistency for subsequent applications. From the time the water is added to the mixture until all of the grout is removed from the box, the mixture must be constantly well stirred with mortar hoes. The grout shall be removed from the box with scoop shovels and applied to the brick in front of men supplied with push brooms, who shall rapidly sweep it lengthwise of the brick into the joints until the joints are practically filled. After the first application has been made and the grout has settled into the joints, and before initial set has taken place, the unfilled portion of the joints shall be filled with the thicker grout, and, if necessary, refilled until the joints remain full to the top. After this has been done the pavement shall be finished to a smooth surface, free from any surplus grout, with a squeegee, which shall be worked over the brick at an angle of about forty-five (45) degrees with the curb. The pavement shall have been thoroughly sprinkled before the first application of grout is made, and shall be kept moist by means of gentle sprinkling until the grout is spread. The top surface, sides, and ends of the brick shall be thoroughly clean at the time the work of filling the joints is done.

Immediately after the grout has taken its initial set the pavement shall be covered with a one (1) inch layer of sand or earth. This layer, immediately after it is placed on the pavement, shall be thoroughly wet by sprinkling and shall be kept wet by sprinkling for at least the five (5) following days. It shall remain on the pavement for at least ten (10) days and shall be removed before traffic is permitted upon the pavement. During this period of ten (10) days or longer, as the engineer may require on account of weather conditions, no traffic shall be allowed upon and no materials shall be placed upon the pavement.

Expansion cushion.[1]—An expansion cushion four (4) inches in depth and of the thickness indicated on the plans shall be constructed along each curb as follows: Suitable provision for the cushion shall be made at the time the brick are laid by setting boards of the proper width and thickness on edge in proper position along the curb. After the brick have been laid, rolled, and grouted, and the grout has well set, the boards shall be carefully removed, so as not to damage the curb or the brick pavement, and the spaces which they occupied shall be filled with blown-oil asphalt heated to a temperature of not less than three hundred (300) degrees Fahrenheit and not more than four hundred (400) degrees Fahrenheit.

ALTERNATE SPECIFICATIONS.

SEPARATE CONCRETE CURBS.

Where the plans call for concrete curbs separate from the foundation they shall be constructed before the subgrade is finally completed and shall have the cross section shown on the plans. Such curbs shall be constructed in sections not less than six (6) feet and not more than twelve (12) feet in length and shall be true to grade and alignment.

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[1] Instead of making a poured joint, as above described, the cushion may be constructed of some of the specially prepared expansion-joint materials, subject to the approval of the engineer as to the material and method of construction.

The specification already given for concrete curbs constructed in combination with the foundation shall also apply to curbs constructed separate from the foundation as regards proportioning, mixing, and placing the concrete, constructing the forms, and all other features of construction which are not covered on the plans or in this specification.

STONE CURBS.

Where stone curbs are required, they shall be hauled and set before the subgrade is finally completed. The curbs shall be set true to line and grade and shall be securely bedded in broken stone, gravel, or firm earth. In preparing the trenches for the curbs great care shall be exercised to see that the material upon which the curb is to be set is well compacted, firm, and hard.

Stone curbing shall be quarried from hard, tough, homogeneous stone. The individual blocks shall have the cross section shown on the plans and shall be not less than four (4) feet in length. Each block shall be free from seams and all other imperfections and shall be neatly dressed and finished on all exposed faces.

CRUSHED-STONE BASE.

Where a crushed-stone base is called for on the plans it shall be constructed after the curbs are set and in two (2) courses of such thickness that the finished base will have the required depth shown on the plans.

The first course of stone shall consist of a single layer of No. 1 stone spread uniformly to a depth of not more than eight (8) inches before compacting. The stone shall be spread by hand from dumping boards or from dump wagons of a type that will distribute each load of stone evenly over that part of the subgrade to be covered by the load.

After the crushed stone of the first course has been spread to the required depth, it shall be rolled until it is thoroughly compacted and firm with a power roller of the macadam type, weighing not less than ten (10) tons and not more than fifteen (15) tons. The rolling shall begin at the curbs and progress gradually toward the crown. All irregularities and depressions that may develop shall be immediately corrected with No. 1 stone, and the rolling shall continue until the stone is well compacted and the surface is uniform in grade and cross section.

The second course of stone shall consist of a single layer of No. 2 stone spread uniformly to a depth not exceeding four (4) inches. The stone shall be spread and rolled in the manner prescribed for the first course. When completed the surface of the second course of crushed stone shall be smooth, firm, well compacted, and continuous, and shall have the cross section and grade indicated by the drawings.

After the second course of stone has been spread, rolled, and completed as above specified, screenings shall be spread uniformly over the surface to a depth of approximately one-half (½) inch. The spreading shall be done with shovels from piles along the road, from dumping boards, or from carts. In no case shall an entire load of screenings be dumped directly upon the second course.

After the screenings are spread they shall be dry rolled until the voids of the second course are filled. The foundation shall then be sprinkled with water from properly constructed sprinkling wagons and rolled with a power roller of the type and weight specified for the first course. The amount of water used shall be sufficient to wet the stone thoroughly, but shall be put on in such quantity and manner as not to wet and soften the subgrade. Screenings shall be added and the sprinkling and rolling continued until the surface ceases to show

the marks of the roller and a grout of water and rock dust flushes ahead of the roller.

After the base is completed, as above specified, no materials or traffic shall be placed or allowed upon it for at least twenty-four (24) hours.

Crushed stone for the base shall be newly broken, of uniform quality throughout, and free from tailings, slaty and flat fragments, soft or disintegrated stone, dirt, or other objectionable matter.

The following designations and sizes shall obtain:

Screenings.—All that portion of the product of the crusher which will pass through a screen having one (1) inch circular openings, including the dust of fracture.

No. 2 stone.—All that portion of the product of the crusher which will be retained on a screen having one (1) inch circular openings and will pass through a screen having circular openings not less than two (2) inches nor greater than two and one-fourth (2¼) inches in diameter.

No. 1 stone.—All that portion of the product of the crusher which will be retained on a screen having circular openings not less than two (2) inches nor greater than two and one-fourth (2¼) inches in diameter, and will pass through a screen having circular openings not less than three (3) inches nor greater than three and one-half (3½) inches in diameter.

A sample of the stone when subjected to the hardness, toughness, and abrasion tests, as described in United States Office of Public Roads Bulletin No. 44, shall satisfactorily meet the following requirements: Hardness not less than ——,[1] toughness not less than ——,[1] and per cent of wear not more than ——.[1]

APPENDIX B.

Method for Inspecting and Testing Paving Brick.[2]

The quality and acceptability of paving brick, in the absence of other special tests mutually agreed upon in advance by the seller on the one side and the buyer on the other side, shall be determined by the following procedure, viz:

(1) *The rattler test,* for the purpose of determining whether the material as a whole possesses to a sufficient degree, strength, toughness, and hardness;

(2) *Visual inspection,* for the purpose of determining whether the physical properties of the material as to dimensions, accuracy and uniformity of shape and color are in general satisfactory, and for the purpose of culling out from the shipment individually imperfect or unsatisfactory brick.

The acceptance of paving brick as satisfactorily meeting one of these tests shall not be construed as in any way waiving the other.

SECTION I.—THE RATTLER TEST.

THE SELECTION OF SAMPLES FOR TEST.

ITEM 1. *Place of sampling.*—In general where a shipment of brick involving a quantity of less than 100,000 is under consideration, the sampling may be done either at the brick factory prior to shipment, or on cars at their destination, or

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[1] Values for hardness, toughness, and per cent of wear should be fixed with a view to securing the very best stone locally available, and not merely to exclude stone of a known unsatisfactory nature.

[2] Recommended by subcommittee on paving brick of the American Society for Testing Materials.

on the street when delivered ready for use. When the quantity under consideration exceeds 100,000, the sampling shall be done at the factory prior to shipment. Brick accepted as the result of tests prior to shipment shall not be liable to subsequent rejection as a whole, but are subject to such culling as is provided for under Section II (Visual inspection).

ITEM 2. *Method of selecting samples.*—In general the buyer shall select his own samples from the material which the seller proposes to furnish. The seller shall have the right to be present during the selection of a sample. The sampler shall endeavor, to the best of his judgment, to select brick representing the average of the lot. No samples shall include brick which would be rejected by visual inspection as provided in Section II, except that where controversy arises, whole tests may be selected to determine the admissibility of certain types or portions of the lot having a characteristic appearance in common. In cases where prolonged controversy occurs between buyer and seller, and samples selected by each party fail to show reasonable concurrence, then both parties shall unite in the selection of a disinterested person to select the samples, and both parties shall be bound by the results of samples thus selected.

ITEM 3. *Number of samples per lot.*—In general one sample of 10 brick shall be tested for every 10,000 brick contained in the lot under consideration, but where the total quantity exceeds 100,000, the number of samples tested may be fewer than 1 per 10,000, provided that they shall be distributed as uniformly as practicable over the entire lot.

ITEM 4. *Shipment of samples.*—Samples which must be transported long distances by freight or express must be carefully put up in packages holding not more than 12 brick each. When more than six brick are shipped in one package, it must be so arranged as to carry two parallel rows of brick side by side, and these rows must be separated by a partition. In event of some of the brick being cracked or broken in transit, the sample shall be disqualified if there are not remaining 10 sound undamaged brick.

ITEM 5. *Storage and care of samples.*—Samples must be carefully handled to avoid breakage or injury. They must be kept dry so far as practicable. If wet when received, or known to have been immersed or subjected to recent prolonged wetting, they shall be dried for at least six hours in a temperature of 100° F. before testing.

THE CONSTRUCTION OF THE RATTLER.

ITEM 6. The machine shall be of good mechanical construction, self-contained, and shall conform to the following details of materials and dimensions, and shall consist of barrel, frame, and driving mechanism as herein described. Accompanying these specifications is a complete drawing (Pl. X) of a rattler which will meet the requirements ,and to which reference should be made.

ITEM 7. *The barrel.*—The barrel of the machine shall be made up of the heads and head liners and staves and stave liners.

The heads may be cast in one piece with the trunnions, which shall be $2\frac{1}{2}$ inches in diameter and shall have a bearing 6 inches in length, or they may be cast with heavy hubs, which shall be bored out for $2\frac{7}{16}$-inch shafts, and shall be keyseated for two keys, each $\frac{1}{2}$ inch by $\frac{3}{8}$ inch and spaced 90° apart. The shaft shall be a snug fit, and when keyed shall be entirely free from lost motion. The distance from the end of the shaft or trunnion to the inside face of the head shall be $15\frac{3}{8}$ inches in the head for the driving end of the rattler and $11\frac{3}{8}$ inches long for the other head, and the distance from the face of the hubs to the inside face of the heads shall be $5\frac{1}{8}$ inches.

The heads shall be not less than $\frac{3}{4}$ inch nor more than $\frac{7}{8}$ inch thick. In outline each head shall be a regular 14-sided polygon inscribed in a circle $28\frac{3}{8}$ inches in diameter. Each head shall be provided with flanges not less than $\frac{3}{4}$ inch thick and extending outward $2\frac{1}{2}$ inches from the inside face of the head to afford a means of fastening the staves. The surface of the flanges of the head must be smooth and must give a true and uniform bearing for the staves. To secure the desired true and uniform bearing the surfaces of the flanges of the head must be either ground or machined. The flanges shall be slotted on the outer edge so as to provide for two $\frac{3}{4}$-inch bolts at each end of each stave, said slots to be $\frac{13}{16}$ inch wide and $2\frac{3}{4}$ inches center to center. Each slot shall be provided with a recess for the bolt head, which shall act to prevent the turning of the same. Between each two slots there shall be a brace $\frac{3}{8}$ inch thick extending down the outward side of the head not less than 2 inches.

There shall be for each head a cast-iron head liner 1 inch in thickness and conforming to the outline of the head, but inscribed in a circle $28\frac{1}{8}$ inches in diameter. This head liner shall be fastened to the head by seven $\frac{5}{8}$-inch cap screws through the head from the outside. Whenever these head liners become worn down $\frac{1}{2}$ inch below their initial surface level at any point of their surface they must be replaced with new ones. The metal of these head liners shall be hard machinery iron and should contain not less than 1 per cent of combined carbon.

The staves shall be made of 6-inch medium steel structural channels $27\frac{1}{4}$ inches long and weighing 15.5 pounds per linear foot. The staves shall have two holes $\frac{13}{16}$ inch in diameter, drilled in each end, the center line of the holes being 1 inch from the end and $1\frac{3}{8}$ inches either way from the longitudinal center line. The spaces between the staves shall be as uniform as practicable, but must not exceed $\frac{5}{16}$ inch.

The interior or flat side of each stave shall be protected by a liner $\frac{3}{8}$ inch thick by $5\frac{1}{2}$ inches wide by $19\frac{3}{4}$ inches long. The liner shall consist of medium steel plate and shall be riveted to the channel by three $\frac{1}{2}$-inch rivets, one of which shall be on the center line both ways and the other two on the longitudinal center line and spaced 7 inches from the center each way. The rivet holes shall be countersunk on the face of the liner and the rivets shall be driven hot and chipped off flush with the surface of the liners. These liners shall be inspected from time to time, and if found loose shall be at once reriveted.

Any test at the expiration of which a stave liner is found detached from the stave or seriously out of position shall be rejected. When a new rattler in which a complete set of new staves is furnished is first put into operation, it shall be charged with 400 pounds of shot of the same sizes, and in the same proportions as provided in Item 9, and shall then be run for 18,000 revolutions at the usual prescribed rate of speed. The shot shall then be removed and a standard shot charge inserted, after which the rattler may be charged with brick for a test.

No stave shall be used for more than 70 consecutive tests without renewing its lining. Two of the 14 staves shall be removed and relined at a time, in such a way that of each pair one falls upon one side of the barrel and the other upon the opposite side, and also so that the staves changed shall be consecutive, but not contiguous; for example, 1 and 8, 3 and 10, 5 and 12, 7 and 14, 2 and 9, 4 and 11, 6 and 13, etc., to the end that the interior of the barrel at all times shall present the same relative condition of repair. The changes in the staves should be made at the time when the shot charges are being corrected, and the record must show the number of charges run since the last pair of newly lined staves was placed in position.

The staves when bolted to the heads shall form a barrel 20 inches long, inside measurement, between head liners. The liners of the staves must be so placed as to drop between the head liners. The staves shall be bolted tightly to the heads by four $\frac{3}{4}$-inch bolts, and each bolt shall be provided with a lock nut, and shall be inspected at not less frequent intervals than every fifth test, and all nuts shall be kept tight. A record shall be made after each inspection showing in what condition the bolts were found.

ITEM 8. *The frame and driving mechanism.*—The barrel shall be mounted on a cast-iron frame of sufficient strength and rigidity to support it without undue vibration. It shall rest on a rigid foundation with or without the interposition of wooden plates and shall be fastened thereto by bolts at not less than four points.

It shall be driven by gearing whose ratio of driver to driven is not less than one to four. The countershaft upon which the driving pinion is mounted shall not be less than $1\frac{15}{16}$ inches in diameter, with bearings not less than 6 inches in length. If a belt drive is used, the pulley shall not be less than 18 inches in diameter and $6\frac{1}{2}$ inches in face. A belt at least 6 inches in width, properly adjusted to avoid unnecessary slipping, should be used.

ITEM 9. *The abrasive charge.*—The abrasive charge shall consist of cast-iron spheres of two sizes. When new, the larger spheres shall be 3.75 inches in diameter and shall weigh approximately 7.5 pounds (3.40 kilos) each. Ten spheres of this size shall be used.

These shall be weighed separately after each 10 tests, and if the weight of any large sphere falls to 7 pounds (3.175 kilos), it shall be discarded and a new one substituted, provided, however, that all of the large spheres shall not be discarded and substituted by new ones at any single time, and that so far as possible the large spheres shall compose a graduated series in various stages of wear.

When new, the smaller sized spheres shall be 1.875 inches in diameter and shall weigh approximately 0.95 pound (0.43 kilo) each. In general the number of small spheres in a charge shall not fall below 245 nor exceed 260. The collective weight of the large and small spheres shall be as nearly as possible 300 pounds. No small sphere shall be retained in use after it has been worn down so that it will pass a circular hole 1.75 inches in diameter, drilled in an iron plate $\frac{1}{4}$ inch in thickness, or weigh less than 0.75 pound (0.34 kilo). Further, the small spheres shall be tested by passing them over the above plate, or shall be weighed after every 10 tests, and any which pass through the plate or fall below the specified weight shall be replaced by new spheres; and provided further, that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that so far as possible the small spheres shall compose a graduated series in various stages of wear. At any time that any sphere is found to be broken or defective it shall at once be replaced.

The iron composing these spheres shall have a chemical composition within the following limits:

Combined carbon, not less than 2.50 per cent.

Graphitic carbon, not more than 0.25 per cent.

Silicon, not more than 1 per cent.

Manganese, not more than 0.50 per cent.

Phosphorus, not more than 0.25 per cent.

Sulphur, not more than 0.08 per cent.

For each new batch of spheres used the chemical analysis must be furnished by the maker or be obtained by the user before introducing into the charge, and unless the analysis meets the above specifications the batch of spheres shall be rejected.

THE OPERATION OF THE TEST.

ITEM 10. *The brick charge.*—The number of brick per test shall be 10 for all bricks of so-called "block size," whose dimensions fall between from 8 to 9 inches in length, 3 to 3¼ inches in breadth, and 3¾ inches to 4¼ inches in thickness.[1] No brick should be selected as part of a regular test that would be rejected by any other requirements of the specifications under which the purchase is made.

ITEM 11. *Speed and duration of revolution.*—The rattler shall be rotated at a uniform rate of not less than 29½ nor more than 30½ revolutions per minute, and 1,800 revolutions shall constitute the test. A counting machine shall be attached to the rattler for counting the revolutions. A margin of not to exceed 10 revolutions will be allowed for stopping. Only one start and stop per test is generally acceptable. If from accidental causes the rattler is stopped and started more than once during a test and the loss exceeds the maximum permissible under the specifications, the test shall be disqualified and another made.

ITEM 12. *The scales.*—The scales must have a capacity of not less than 300 pounds and must be sensitive to one-half of an ounce and must be tested by a standard test weight at intervals of not less than every 10 tests.

ITEM 13. *The results.*—The loss shall be calculated in percentage of the initial weight of the brick composing the charge. In weighing the rattled brick any piece weighing less than 1 pound shall be rejected.

ITEM 14. *The records.*—A complete and continuous record shall be kept of the operation of all rattlers working under these specifications. This record shall contain the following data concerning each test made:

1. The name of the person, firm, or corporation furnishing each sample tested.
2. The name of the maker of the brick represented in each sample tested.
3. The name of the street or contract which the sample represented.
4. The brands or marks upon the bricks by which they were identified.
5. The number of bricks furnished.
6. The date on which they were received for test.
7. The date on which they were tested.
8. The drying treatment given before testing, if any.
9. The length, breadth, and thickness of the bricks.
10. The collective weight of the 10 large spherical shot used in making the test at the time of their last standardization.
11. The number and collective weight of the small spherical shot used in making the test at the time of their last standardization.
12. The total weight of the shot charge after its last standardization.
13. Certificate of the operator that he examined the condition of the machine as to staves, liners, and any other parts affecting the barrel and found them right at the beginning of the test.
14. Certificate of the operator of the number of charges tested since the last standardization of shot charge.
15. The time of the beginning and ending of each test and the number of revolutions made by the barrel during the test as shown by the indicator.
16. Certificate of the operator as to number of stops and starts made in each test.

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[1] Where brick of larger or smaller sizes than the dimensions given above for blocks are to be tested, the same number of bricks per charge should be used, but allowance for the difference in size should be made in setting the limits for average and maximum rattler loss.

17. The initial collective weight of the 10 brick composing the charge and their collective weight after rattling.

18. The loss calculated in per cents of the initial weight; and the calculation itself.

19. The number of broken brick and remarks upon the portions which were included in the final weighing.

20. General remarks upon the test and any irregularities occurring in its execution.

21. The date upon which the test was made.

22. The location of the rattler and name of the owner.

23. The certificate of the operator that the test was made under the specifications of the American Society for Testing Materials and that the record is a true record.

24. The signature of the operator or person responsible for the test.

25. The serial number of the test.

In event of more than one copy of the record of any test being required, they may be furnished on separate sheets and marked duplicates, but the original record shall always be preserved intact and complete.

ACCEPTANCE AND REJECTION OF MATERIAL.

ITEM 15. *Basis of acceptance or rejection.*—Paving brick shall not be judged for acceptance or rejection by the results of individual tests, but by the average of not less than five tests. Where a lot of brick fails to meet the required average it shall be optional with the buyer whether the brick shall be definitely rejected or whether they may be regraded and a portion selected for further test as provided in Item 16.

ITEM 16. *Range of fluctuation.*—Some fluctuation in the results of the rattler test, both on account of variation in the brick and in the machine used in testing, are unavoidable, and a reasonable allowance for such fluctuations should be made wherever the standard may be fixed.

In any lot of paving brick, if the loss on a test computed upon its initial weight exceeds the standard loss by more than 2 per cent, then the portion of the lot represented by that test shall at once be resampled and three more tests executed upon it, and if any of these three tests shall again exceed by more than 2 per cent the required standard, then that portion of the lot shall be rejected.

If in any lot of brick two or more tests exceed the permissible maximum, then the buyer may, at his option, reject the entire lot, even though the average of all the tests executed may be within the required limits.

ITEM 17. *Fixing of standards.*—The percentage of loss which may be taken as the standard will not be fixed in these regulations, and shall remain within the province of the contracting parties. For the information of the public the following scale of average losses is given, representing what may be expected of tests executed under the foregoing specifications:

	General average loss.	Maximum permissible loss.
	Per cent.	*Per cent.*
For brick suitable for heavy traffic	22	24
For brick suitable for medium traffic	24	26
For brick suitable for light traffic	26	28

Which of these grades should be specified in any given district and for any given purpose is a matter wholly within the province of the buyer, and should be governed by the kind and amount of traffic to be carried, and the quality of paving brick available.

ITEM 18. *Culling and retesting.*—Where, under items 15 and 16 a lot or portion of a lot of brick is rejected, either by reason of failure to show a low enough average test or because of tests above the permissible maximum, the buyer may at his option permit the seller to regrade the rejected brick, separating out that portion which he considers at fault and retaining that which he considers good. When the regrading is complete the good portion shall be then resampled and retested, under the original conditions, and if it fails again either in average or in permissible maximum, then the buyer may definitely and finally reject the entire lot or portion under test.

ITEM 19. *Payment of cost of testing.*—Unless otherwise specified, the cost of testing the material as delivered or prepared for delivery, up to the prescribed number of tests for valid acceptance or rejection of the lot, shall be paid by the buyer. (See also item 23.) The cost of testing extra samples made necessary by the failure of the whole lot or any portion of it shall be paid by the seller, whether the material is finally accepted or rejected.

SECTION II.—VISUAL INSPECTION.

It shall be the right of the buyer to inspect the brick, subsequent to their delivery at the place of use, and prior to or during laying, to cull out and reject upon the following grounds:

ITEM 20. All brick which are broken in two or chipped in such a manner that neither wearing surface remains substantially intact, or that the lower or bearing surface is reduced in area by more than one-fifth. Where brick are rejected upon this ground, it shall be the duty of the purchaser to use them so far as practicable in obtaining the necessary half brick for breaking courses and making closures, instead of breaking otherwise whole and sound brick for this purpose.

ITEM 21. All brick which are cracked in such a degree as to produce defects such as defined in item 20, either from shocks received in shipment and handling or from defective conditions of manufacture, especially in drying, burning, or cooling, unless such cracks are plainly superficial and not such as to perceptibly weaken the resistance of the brick to its conditions of use.

ITEM 22. All brick which are so offsize, or so misshapen, bent, twisted, or kiln marked that they will not form a proper surface as defined by the paving specifications, or align with other brick without making joints other than those permitted in the paving specifications.

ITEM 23. All brick which are obviously too soft and too poorly vitrified to endure street wear. When any disagreement arises between buyer and seller under this item, it shall be the right of the buyer to make two or more rattler tests of the brick which he wishes to exclude, as provided in item 2, and if in either or both tests the brick fall beyond the maximum rattler losses permitted under the specifications, then all brick having the same objectionable appearance may be excluded, and the seller must pay for the cost of the test. But if under such procedure, the brick which have been tested as objectionable shall pass the rattler test, both tests falling within the permitted maximum, then the buyer can not exclude the class of material represented by this test and he shall pay for the cost of the test.

ITEM 24. All bricks which differ so markedly in color from the type or average of the shipment as to make the resultant pavement checkered or disagreeably mottled in appearance. This item shall not be held to apply to the normal variations in color which may occur in the product of one plant among brick which will meet the rattler test as referred to in items 15, 16, and 17, but shall apply only to differences of color which imply differences in the material of which the brick are made, or extreme differences in manufacture.

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 247

Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.
July 20, 1915.

(PROFESSIONAL PAPER.)

A DISEASE OF PINES CAUSED BY CRONARTIUM PYRIFORME.

By George G. Hedgcock, *Pathologist*, and William H. Long, *Forest Pathologist*, *Investigations in Forest Pathology.*

CONTENTS.

HISTORY OF THE FUNGUS.

In 1875 Peck (10)[1] described as a new species under the name *Peridermium pyriforme* a caulicolous or stem-inhabiting Peridermium with obovate to pyriform spores from a specimen collected by J. B. Ellis (No. 2040). In 1882 Ellis issued in his North American Fungi under No. 1021 a caulicolous Peridermium which he called "*Peridermium pyriforme* on small branches of *Pinus virginiana*," and in the Ellis Herbarium, now at the New York Botanical Garden is a specimen labeled "*Peridermium pyriforme* on small branches of *Pinus rigida*, Newfield, New Jersey, May, 1890." Both of these latter specimens appear to be *Peridermium comptoniae;* at any rate, neither of them is the true *P. pyriforme* originally described by Peck. Arthur and Kern (1) in 1906 described as *P. pyriforme* Peck what is now known as *P. comptoniae.*

In 1913 the writers received from Prof. E. Bethel a caulicolous species of Peridermium on *Pinus contorta*, which they described as a

[1] Reference is made by number to "Literature cited," p. 20.

NOTE.—This bulletin discusses an important disease of pines which is now for the first time fully described. It is intended for circulation among botanists, foresters, nurserymen, State inspectors, and horticulturists.

new species, *Peridermium betheli* (6). The type material *P. pyriforme* was not accessible at the time the article was prepared, as all of Peck's specimens were packed up and in transit from the old to the new quarters of the New York State Museum. The writers therefore had to depend upon Arthur and Kern's published statement concerning this species (1, p. 420). The spore measurements also of the typical *P. pyriforme* did not correspond, since the length of spores of the eastern species as given by Peck in his original description was too great. While this article by the writers (6) was in press, Arthur and Kern published an article (2) in which they discarded their earlier interpretation of *P. pyriforme* and admitted that there is a species of Peridermium with typical "pyriform, obovate, or oblong-pyriform spores," just as Peck had originally described it in 1875 (10), and that their original assignment of *P. pyriforme* Peck to what is now known as *P. comptoniae* was an error. They also suggested that the alternate stages of this Peridermium would probably be found on species of Comandra.

Orton and Adams (9), in 1914, published an article on Peridermium from Pennsylvania, in which they discussed *Peridermium comptoniae* and *P. pyriforme*. They described the finding of a caulicolous species of Peridermium at Charteroak, Huntingdon County, Pa., on the trunks of *Pinus pungens*, which proved to be the true *Peridermium pyriforme* of Peck. Subsequently *Cronartium comandrae* was found within 40 feet of the infected pines and the conclusion reached that this Cronartium is the alternate stage of *Peridermium pyriforme*. They also state that *P. betheli* is probably a synonym of *P. pyriforme*. In May, 1914, Arthur and Kern in a general discussion of the North American species of Peridermium inhabiting pines (3) gave the synonymy of *P. pyriforme*, a technical description, and an explanation of their change of opinion regarding the species.

In June, 1914, the writers published culture data (8) showing that successful sowings of the æciospores of *Peridermium pyriforme* had been made on *Comandra umbellata*, thus completing the life cycle of this interesting rust and proving that its alternate stage was the Cronartium found on Comandra.

MORPHOLOGY OF THE FUNGUS.

The macroscopic characters of *Peridermium pyriforme* are practically identical on all the hosts examined by the writers, but there are some differences in the microscopic characters, especially in the shape and size of the æciospores. This difference in size and shape of the spores may be due to the influence of the æcial host; that is, they may vary according to the species of Pinus which the Peridermium inhabits. In specimens of the rust on *Pinus contorta* (Pl. I,

fig. 4) from Colorado, some of the æciospores are very short and slightly acuminate, while many are ellipsoid or even globoid (Pl. I, fig. 3). In specimens on *Pinus pungens* from Pennsylvania many of the spores are nearly twice as long as those from *Pinus contorta*, the acumination is very marked, and the spores are rarely ellipsoid (Pl. I, fig. 2).

Peck's type material of *Peridermium pyriforme* is in the New York State Museum, at Albany, N. Y. It consists of a split branch 4 cm. long, 1 cm. thick at one end and 0.5 cm. thick at the other; the weak, fragile peridia barely protrude beyond the bark. The split surface of the twig is glued to the yellow paper bearing one of the legends. The specimen is in fairly good condition and most of the essential characters, both macroscopic and microscopic, can be determined from it. What appears to be the other half of this specimen is at the New York Botanical Garden, Bronx Park, N. Y., but it is much insect eaten and but little can be determined from it.

The type material at Albany bears the following legends on the box: "*Peridermium pyriforme*, Newfield, N. J. Ellis #2040." On the original wrapper is "*Peridermium pyriforme* on pine limbs in the spring, Newfield, N. J. .0015–.0025. No. 2040 Ellis." This legend is in two parts. The name is in Peck's handwriting, with a drawing of a spore and size of spores in pencil, while the host, location, and number of the specimen are in ink and are in Ellis's handwriting. The word "type" is not in the original legend. The following is Peck's original description of *Peridermium pyriforme* (10) and his remarks on the same:

> Peridia erumpent, large, white when evacuated, the cells subrotund, with a paler margin, marked with radiating striations, spores obovate, pyriform, or oblong-pyriform, acuminate below, .0015–.0025 inch long.
>
> Bark of pine branches. The specimen is labeled "Newfield, N. J.," but Mr. Ellis informs me that it may have been collected in Georgia and placed by accident among his New Jersey specimens.
>
> In the dried specimens the peridia are mostly compressed, about one-fourth of an inch long, and scarcely exserted above the surface of the bark. The spores are pale yellow, but probably they are more highly colored when fresh. The acumination is generally acutely pointed, and it is sometimes so elongated as to make the spore appear clavate. It is one of the most distinctive features of the species.

SYNONYMY AND DESCRIPTION OF THE FUNGUS.

Cronartium pyriforme (Peck) Hedgc. and Long, 1914, Alternate Stage of Peridermium Pyriforme.

Cronartium asclepiadeum thesii Berk., 1845, *in* Lond. Jour. Bot., v. 4, p. 311.

Peridermium pyriforme Peck, 1875, *in* Bul. Torrey Bot. Club, v. 6, No. 2, p. 13.

Caeoma comandrae Peck, 1884, *in* Bul. Torrey Bot. Club, v. 11, No. 5, p. 50.

Cronartium thesii (Berk.) Lagerh., 1895, *in* Tromsø Mus. Aarsh., v. 17, p. 94.

Peridermium betheli Hedgc. and Long, 1913, *in* Phytopathology, v. 3, No. 4, p. 251.

Pycnia unknown.

Æcia caulicolous, appearing on branches or trunks, forming lesions or fusiform swellings 2 to 30 cm. long (Pl. II, fig. 3); sori scattered or somewhat confluent in small groups, rounded or irregular, 2 to 6 mm. long by 2 to 4 mm. wide by 1 to 2 mm. high; peridium usually only slightly protruding from the bark, bladdery, subhemispherical, rupturing irregularly along the top and sides, without concolorous processes, about 2 cells thick, outer surface minutely and rather closely verrucose, inner surface also rather closely verrucose but with longer tubercles; peridial cells with a radially striate margin, not easily torn apart, those of the inner layer often irregularly compressed, walls thin, 2 to 4 μ in thickness, lumen large; cells in the upper portion of the peridium ovate, 15 to 20 by 22 to 42 μ, in the lower portion ellipsoid to ovate, 16 to 20 by 40 to 60 μ; æciospores very variable in size and shape, subglobose, obovate, ellipsoid, pyriform or even subclavate on some hosts, more or less acuminate at the basal end, occasionally at both ends (Pl. I, figs. 1, 2, and 3), 15 to 27 by 25 to 74 μ, average for 160 æciospores 21.6 by 57.5 μ, walls colorless, thicker at both ends than in the middle, 2 to 4 μ thick, rather densely verrucose with small irregular tubercles which in narrow ellipsoid spores are often arranged in irregular almost parallel lines or with a ridgelike marking, which gives the surface a reticulate appearance, no smooth spot present; cell contents of the æciospores orange yellow when fresh.

Found on *Pinus contorta* Loud., *P. divaricata* (Ait.) Du Mont du Cours., *P. ponderosa* Laws., *P. ponderosa scopulorum* Sudw., *P. pungens* Michx., and *Pinus* sp.

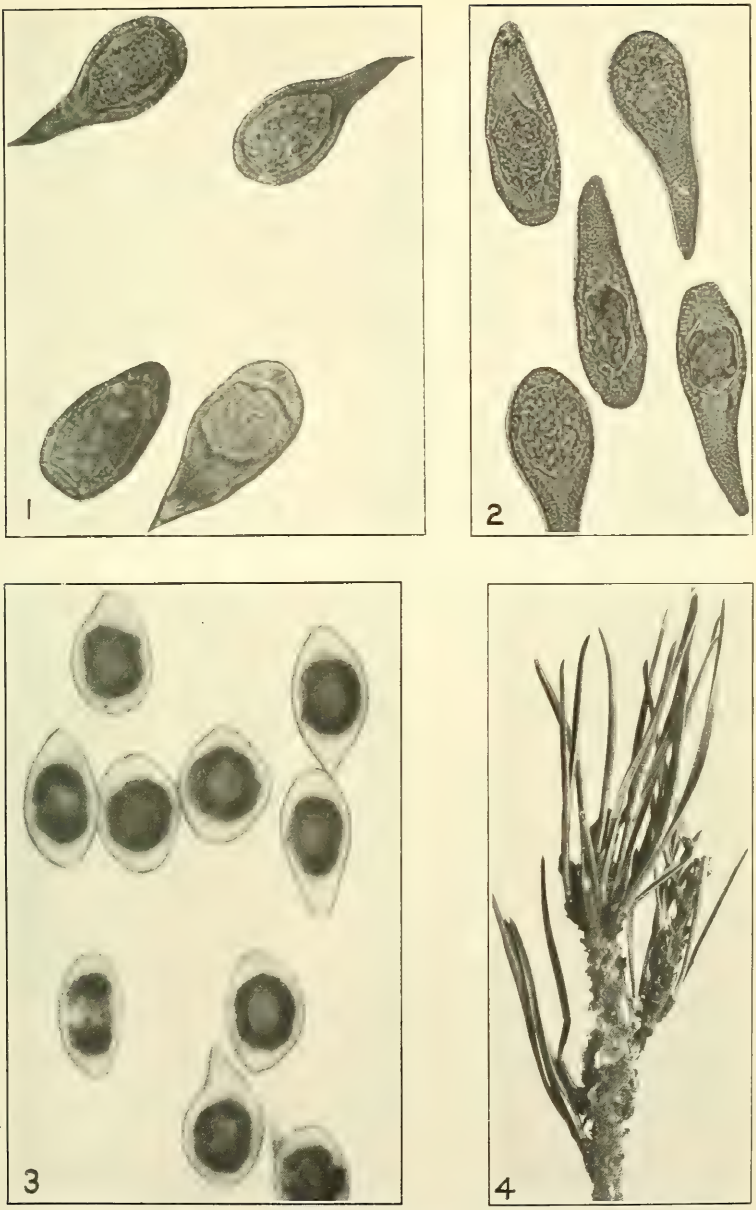
Uredinia amphigenous or hypophyllous,[1] scattered or densely gregarious, on pallid areas, pustular, 125 to 200 μ in diameter, dehiscent by a central opening or pore; peridium delicate; urediniospores broadly elliptical to globoid, 16 to 21 by 19 to 25 μ, average for 10 spores 17.8 by 20 μ, walls nearly colorless and sparsely but minutely echinulate, 1.5 to 2 μ thick.

Telial columns amphigenous or hypophyllous,[1] caulicolous, cylindrical, 80 to 115 μ thick, about 1 mm. in length; teliospores oblong to cylindrical, obtuse to truncate at one or both ends, 12 to 16 by 28 to 40 μ, average for 10 spores 14 by 32.7 μ, walls smooth, nearly colorless.

Found on *Comandra pallida* A. DC., *C. umbellata* (L.) Nutt., and *C. richardsiana* Fernald (?).

In the preceding description by the junior writer, the æcial characters (Peridermium) are taken from the specimens named in Table II on *Pinus contorta*, *P. ponderosa*, *P. ponderosa scopulorum*, and *P. pungens*. The uredinial and telial characters (Cronartium) are

[1] Amphigenous on *Comandra pallida*, hypophyllous on *Comandra umbellata*.



ÆCIOSPORES OF CRONARTIUM PYRIFORME AND A TWIG OF PINUS CONTORTA.

FIG. 1.—Æciospores of *Cronartium pyriforme*, from the type specimen on *Pinus* sp. at Albany, N. Y. (Microphotograph.) FIG. 2.—Æciospores of *Cronartium pyriforme* from *Pinus pungens*, collected near Greenwood Furnace, Pa. (Microphotograph.) These closely resemble the type. FIG. 3.—Æciospores of *Cronartium pyriforme* from *Pinus contorta*, near Eldorado Springs, Colo., from the same tree as the type of *Peridermium betheli* (microphotograph), showing the variation in the shape of the spores on this pine from those of the type specimen in figure 1. FIG. 4.—A twig of *Pinus contorta*, showing the æcia and peridia of the fungus *Peridermium pyriforme* (*P. betheli*) on a slightly swollen portion. (About natural size.)

INJURIES TO PINES PRODUCED BY CRONARTIUM PYRIFORME.

FIG. 1.—A slight hypertrophy of the trunk of a small tree of *Pinus pungens* produced by the æcia of *Cronartium pyriforme*. (About one-third natural size.) FIG. 2.—Openings produced by the rupturing of the bark of *Pinus pungens* by the maturing of the æcia of *Cronartium* (*Peridermium*) *pyriforme*. (About one-third natural size.) FIG. 3.—A twig of *Pinus contorta*, showing a fusiform swelling produced by *Cronartium* (*Peridermium*) *pyriforme* on this species of tree. Similar fusiform swellings are produced by the fungus on *Pinus ponderosa*. (About one-half natural size.)

taken from specimens of the fungus on leaves of *Comandra umbellata* obtained by inoculations with æciospores from *Pinus pungens* from Greenwood Furnace, Pa.

INOCULATION EXPERIMENTS WITH THE FUNGUS.

Table I gives complete inoculation data for this fungus on *Comandra umbellata.* Successful inoculations were made with æciospores from two hosts, *Pinus ponderosa* and *Pinus pungens*, collected from three widely separated localities in the States of Washington, California, and Pennsylvania. In each instance control plants of the same species were used, and all remained free from infection. Unsuccessful inoculations were made with æciospores from *Pinus contorta* (*Peridermium betheli*) both during 1913 and 1914. In 1914 the failure to infect might have been due to the extreme high temperature of the greenhouse at the time the inoculation experiments were performed. However, the failure for two successive seasons to infect Comandra with the æciospores from *Pinus contorta* may indicate that the rust on this host is a different species from *Peridermium pyriforme*, since the shape and size of the æciospores (*P. betheli*; Pl. I, fig. 3) from *Pinus contorta* are different from those of the type specimen of this rust (Pl. I, fig. 1). The writers, in the absence of proof from inoculations, assume for the present that these morphological differences may be due to the host and therefore are not of sufficient importance to warrant classifying *Peridermium betheli* as distinct from *P. pyriforme*.

TABLE I.—*Results of inoculations with the æciospores of Cronartium pyriforme.*

Æcial host, serial number, and locality.	Species inoculated.	Date of inoculation.	Results.			Collector.
			Uredinia.	Telia.	Degree of infection.	
Pinus contorta:		1913				
8500, Eldorado Springs, Colo.	Comandra umbellata	June 18			No infection	Bethel.
8500,[1] Eldorado Springs, Colo.	Comptonia asplenifolia	do			do	Do.
8514, Allenspark, Colo.	Comandra umbellata	June 27			do	Do.
Do	Castilleja linearis	do			do	Do.
Pinus ponderosa:		1914	1914	1914		
12467, Wenatchee, Wash.	Comandra umbellata	May 27	June 5	June 28	Sparse[2]	Fisher.
Do	do	May 30	June 9	July 4	do	Do.
12468, Rocky Gulch, Cal.	do	May 28	June 6	July 5	do	Boyce.
Pinus pungens:						
15444, Greenwood Furnace, Pa.	do	May 29	June 7	June 30	Very abundant.	Hedgcock.
15455, Greenwood Furnace, Pa.	do	May 30	June 10	July 15	do	Do.
Do	do	do	June 11	do	do	Do.
15462, Greenwood Furnace, Pa.	do	June 1	do	July 1	Sparse	Do.
Do	do	June 2	June 12	July 4	Abundant[3]	Do.
Do	do	do	June 13	July 8	do	Do.
Do	do	June 3	do	July 5	Sparse	Do.
Pinus contorta:						
15550, Eldora, Colo.	do	July 3			No infection[4]	Do.
Do	Ribes longiflorum	do			do	Do.

[1] Type of *Peridermium betheli*.
[2] Sparse here means less than six sori.
[3] Telia immature.
[4] Inoculation made in very hot weather.

A study of Table II and of figures 1 and 2 of Plate I shows some very interesting facts. For instance, the shape and size of the spores from the type material (Pl. I, fig. 1) and those from *Pinus pungens* (Pl. I, fig. 2) are practically identical, since the range in size for 20 spores of the type is 19 to 25.6 μ by 41.6 to 73.6 μ with an average for 20 spores of 23.4 by 58.6μ, and for 20 spores from *Pinus pungens* the range is 19 to 25.6 μ by 42 to 73.6 μ with an average for 20 spores of 23.1 by 59.1 μ. This close similarity in size and shape would indicate that the type may have been on *Pinus pungens*, but this does not seem probable if the type really came from Newfield, N. J., as *Pinus pungens* has not been reported from this locality, although Britton (4) reports it as abundant 1 mile east of Sergeantsville, in Hunterdon County. It is possible that sporadic or introduced specimens of *Pinus pungens* may have been growing near Newfield at the time the collection of the type specimen of *Peridermium pyriforme* was made. The alternate stage of the rust, *Cronartium pyriforme*, on *Comandra umbellata* was collected at Newfield, N. J., by Ellis in August, 1879, and issued by him in North American Fungi under the number 1082. This indicates that the type material of *Peridermium pyriforme* came from New Jersey.

TABLE II.—*Measurements, shape, etc., of the æciospores of Cronartium pyriforme.*

Æcial host, serial number, and locality.	Measurement (microns).		Shape.	Acumination.
	Range in size.	Average for 20 spores.		
Pinus pungens:				
15462, Greenwood Furnace, Pa.	19 to 25.6 by 42 to 73.6.	23.1 by 59.1..	Obovate or pyriform to subclavate or spatulate.	Often very long (Pl. I, fig. 2).
Pinus sp.:				
Type, Newfield, N. J. (?).	19 to 25.6 by 41.6 to 73.6.	23.4 by 58.6..	Obovate to pyriform or subclavate.	Often very long (Pl. I, fig. 1).
Pinus ponderosa:				
15556, near Darby, Mont..	19 to 25.6 by 38 to 64.	22.4 by 48.6..	Obovate to pyriform or rarely ellipsoid.	Often not very pronounced.
12467, Wenatchee, Wash..	18 to 25.6 by 38 to 64.	21.1 by 51.5..	Obovate to pyriform.	Do.
12468, Rocky Gulch, Cal..	20.8 to 25.6 by 35 to 70.4.	23.9 by 54.5..	......do............	Do.
Pinus ponderosa scopulorum:				
12470, Crook National Forest, Ariz.	19 to 27 by 32 to 64.	21.8 by 44.3..	Ellipsoid or obovate to pyriform.	Usually very short.
Pinus contorta:				
15550, Eldora, Colo.......	15 to 25.6 by 25 to 45.	18.1 by 40.2..	......do............	Usually very short (Pl. I, fig. 3).
8500, Eldorado Springs, Colo.	15 to 26 by 25 to 48.	20 by 43.....	......do............	Usually very short.

The senior writer, during August, 1914, visited Newfield and several other localities in the same region. He found the same species of pine here that are known to occur in southern New Jersey and that probably were present at the time of the Ellis collection, viz, *Pinus echinata*, *P. rigida*, and *P. virginiana*. None of these were found by him to be diseased with the Peridermium of *Cronartium pyriforme.*

Comandra umbellata observed in a number of these localities was also free from the rust.

In 1914 the senior writer found *Pinus pungens, P. rigida,* and *P. virginiana* closely associated in a mixed forest near Greenwood Furnace, Pa. In this instance *Pinus pungens* was attacked by *Peridermium pyriforme* so badly that in some places more than 50 per cent of the trees were killed, and although *Comandra umbellata* plants bearing the telial form of the rust were present in abundance, no pines of either of the other species were diseased. This indicates that these two species of trees are immune and that neither can be the host for the type specimen that Ellis found at Newfield. Of the five species of pines known to be the æcial host of this fungus, not one is a strictly three-needle pine. All have either two or two to three needles in the leaf clusters. This makes it seem improbable that *Pinus rigida* was the host of the type material. *Pinus echinata* is a two to three needle pine found in southern New Jersey, and this species may have been the host of Ellis's type.

The cultural work done by the writers with *Peridermium pyriforme* Peck proving it to be the æcial stage of *Cronartium pyriforme* (Peck) Hedgc. and Long on species of Comandra completes the life history of all the caulicolous species of Peridermium as now recognized in the United States. There are four native and one introduced species and each constitutes the æcial stage of a species of Cronartium:

(1) *Peridermium pyriforme,* which is the æcial stage of *Cronartium pyriforme.*

(2) *Peridermium cerebrum* Peck is the æcial stage of *Cronartium cerebrum* (Peck) Hedgc. and Long on species of Quercus and Castanopsis. This is a well-recognized eastern species and, including its western form, *Peridermium harknessii* Moore, is the only native gall-forming Peridermium in the United States. *P. harknessii* on *Pinus radiata* Don is synonymous with *Peridermium cerebrum,* since it is associated with *Cronartium cerebrum* on *Quercus agrifolia* Née on the Monterey Peninsula in California. The other forms of *Peridermium harknessii* may not belong here, and until cultural proof of their identity with *P. cerebrum* is obtained, the forms on *Pinus ponderosa, Pinus contorta,* and other western pines remote from species of Quercus and Castanopsis can only be doubtfully referred here.

(3) *Peridermium comptoniae* (Arth.) Orton and Adams, a well-known eastern species, usually occurring on the pitch pine (*Pinus rigida* Mill.) in the eastern and northeastern United States, but also attacking two to three needle species, is the æcial stage of *Cronartium comptoniae* Arth. which attacks *Comptonia peregrina* (L.) Coult. and *Myrica gale* L.

(4) *Peridermium filamentosum* Peck on *Pinus ponderosa* and *Pinus contorta* is the æcial stage of *Cronartium filamentosum* (Peck) Hedgc., which attacks a number of species of Castilleja in the western United States over a wide region, ranging from the Rocky Mountains to the Pacific coast. *Peridermium stalactiforme* Arth. and Kern and *Cronartium coleosporioides* (Dietel and Holway) Arth. and Kern are synonymous with this species.

(5) *Peridermium strobi* Kleb., an introduced species, is the æcial stage of *Cronartium ribicola* Fisch. de Waldh., which attacks many species of Ribes. In Europe this Peridermium attacks several species of white (5-needle) pine. In the United States it has been found on only one species, *Pinus strobus* L.

For a number of years Prof. E. Bethel has collected from the leaves of *Ribes longiflorum* at Denver, Boulder, and elsewhere in Colorado a species of Cronartium which is apparently not identical with the European *Cronartium ribicola.* The senior writer collected abundant specimens of the uredinial and telial forms of this rust both at Boulder and Denver, Colo., in October, 1914. The telia of this Cronartium are larger, more abundant, and much more conspicuous than those of the European species. Although the fungus has been epidemic for several years on the Chautauqua grounds near Boulder, two young white pines (*Pinus strobus*) on the grounds not far from the diseased Ribes were free from the disease. This species apparently is able to winter over on Ribes plants in the uredinial form. It may yet be found that the æcial form is a Peridermium on one of our native pines.

DISTRIBUTION OF THE FUNGUS.

DISTRIBUTION OF THE ÆCIAL FORM.[1]

The æcial form of the fungus, *Peridermium pyriforme,* is widely distributed in the United States, having been found in 10 States:

FIG. 1.—Outline sketch map of the United States, showing the known distribution of *Cronartium pyriforme.* Localities where collections of the different forms of the fungus have been made are indicated as follows: ∨, Æcial form on species of pines; ∧, uredinial and telial forms on species of Comandra; ×, all forms.

Arizona, California, Colorado, Montana, New Jersey, Pennsylvania, South Dakota, Washington, Wisconsin, and Wyoming (fig. 1); and when a more careful search is made for the fungus, in the light of our present knowledge, it will no doubt be found to have a much more general distribution in this country. It has also been found in Alberta and British Columbia.

[1] All specimens cited except those marked with a star (*) have been examined by one of the writers.

DISTRIBUTION IN THE DOMINION OF CANADA.

Alberta.—On *Pinus contorta* (*P. murrayana*): * Devil's Lake, Banff, by Holway (3, p. 127), in 1907.

British Columbia.—On *Pinus ponderosa:* * Vernon, by Brittain, in 1913.

DISTRIBUTION IN THE UNITED STATES.

New Jersey.—On *Pinus* sp.: (Type) Newfield, by Ellis (2040), in 1882 (Herbarium New York State Museum).

Pennsylvania.—On *Pinus pungens:* Charteroak, by Orton and Adams, in 1913 (F. P.[1] 15129); Greenwood Furnace, by Hedgcock, in 1914 (F. P. 15444, 15455, and 15462); Petersburg, Huntingdon County, by Hedgcock, in 1914 (F. P. 15483).

Wisconsin.—On *Pinus divaricata:* * Douglas County, by Davis.

South Dakota.—On *Pinus ponderosa scopulorum:* * Rockerville, by White; Black Hills near Custer, by Hedgcock and Phillips (F. P. 15826) and by Hedgcock (F. P. 15801), in 1914.

Wyoming.—On *Pinus contorta:* Dubois, by C. E. Taylor, in 1914 (F. P. 15797).

Colorado.—On *Pinus contorta* (*P. murrayana*): * Gatos (collector not given), in 1906 (3, p. 126–127); Eldorado Springs (F. P. 8500), type of *Peridermium betheli*, Lake Eldora (F. P. 8511), Allenspark (F. P. 8502 and 8514), Arrow (F. P. 8515 and 8494), by Bethel, in 1913; Eldora (F. P. 15550), by Bethel, in 1914.

On *Pinus ponderosa scopulorum:* Monument, by Hedgcock, in 1912; Allenspark, by Bethel, in 1913 (F. P. 8504, 8505, 8510, and 8451).

Montana.—On *Pinus ponderosa:* Darby, by Weir, in 1914 (F. P. 15556).

Washington.—On *Pinus ponderosa:* Wenatchee, by D. F. Fisher, in 1914 (F. P. 12467).

On *Pinus* sp.: * Seattle, by Bonser (3, p. 127), in 1906.

California.—On *Pinus ponderosa:* Trinity National Forest, by Box, in 1912; Rocky Gulch, Siskiyou County, by Meinecke, in 1913; by Boyce, in 1914 (F. P. 12468); Mills Ranch, Goosenest Mountain, Siskiyou County, by Boyce, in 1914 (F. P. 15678 and 15680); Castella, Shasta County; Weaverville and Brown Creek, Trinity County, by Boyce, in 1914.

Arizona.—On *Pinus ponderosa scopulorum:* Crook National Forest, by Swift, in 1914 (F. P. 12470).

DISTRIBUTION OF THE UREDINIAL AND TELIAL FORMS.

Cronartium pyriforme, representing both the uredinial and telial forms of the fungus, has been collected more frequently and over a greater range of terrritory than the æcial form. It has been found in

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[1] Forest-Pathology Investigations number.

Quebec and Ontario in the Dominion of Canada and in the United States in the following States: California, Colorado, Illinois, Massachusetts, Michigan, Missouri, Montana, Nebraska, New Jersey, New York, North Dakota, Ohio, Pennsylvania, South Dakota, Utah, Washington, Wisconsin, and Wyoming (fig. 1).

DISTRIBUTION IN THE DOMINION OF CANADA.[1]

Quebec.—On *Comandra umbellata.*[2]—Seven Islands, by C. B. Robinson (858, Plants of Quebec).

Ontario.—On *Comandra umbellata.*[2]—London, by J. Dearness (2443, Sydow Uredineen and 3419, Fungi Columbiani); and Point Abino, by J. J. Davis (Herbarium New York Botanical Garden).

DISTRIBUTION IN THE UNITED STATES.

Vermont.—On *Comandra umbellata:* Between Essex Junction and Burlington, by Hedgcock (F. P. 8539 and 8655); locality not given, by A. J. Grout (Herbarium New York Botanical Garden).

Massachusetts.—On *Comandra umbellata:* Magnolia, by Seymour and Earle (210–a and 210–b, Economic Fungi).

New York.—On *Comandra umbellata:* Syracuse (Ex. Herbarium L. M. Underwood); Ithaca, by H. S. Jackson (1458, Flora North America); Mount Defiance, by Peck (Herbarium New York State Museum).

New Jersey.—On *Comandra umbellata:* Newfield, by Ellis (1082, Ellis and Everhart, North American Fungi).

Pennsylvania.—On *Comandra umbellata:* Charteroak, Huntingdon County, by Orton, Adams, and Kirk (9, p. 25); Petersburg, Huntingdon County, by Hedgcock (F. P. 15637). Greenwood Furnace, Huntingdon County, by Hedgcock (F. P. 15653, 15654, and 15657).

Ohio.—On *Comandra umbellata:* Cleveland, by B. T. Galloway.

Illinois.—On *Comandra umbellata:* Oregon, by M. B. Waite (85, 134, 176, and 366).

Missouri.—On *Comandra pallida:* Emma, by C. H. Demetrio (4310, Rabenhorst-Paczschke, Fungi Europæi et Extra-Europæi).

Michigan.—On *Comandra umbellata:* Ann Arbor, by Holway (504, North American Uredinales); Ann Arbor, by F. L. Scribner; Roscommon, P. Spaulding (F. P. 15681).

Wisconsin.—On *Comandra umbellata:* Racine, by J. J. Davis; The Dells, by Underwood (Herbarium New York Botanical Garden).

Nebraska.—On *Comandra pallida:* Dismal River, by Webber (784, Fungi Nebraskenses); Hat Creek basin, by Webber (776, Fungi Nebraskenses); Lincoln, by R. J. Pool (F. P. 17045).

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[1] All specimens here listed are in the mycological collections of the United States Department of Agriculture unless otherwise noted.

[2] These species probably should be *Comandra richardsiana* Fernald, since the collections were made in the range of *C. richardsiana* and out of the range of *C. umbellata* as now recognized.

Wyoming.—On *Comandra pallida:* Big Horn Mountains, by Williams and Griffiths (298–a, West American Fungi); Bear Lodge Mountains, by Griffiths and Carter (298, West American Fungi); Centennial, by E. T. and E. Bartholomew (3705, Fungi Columbiani); near Medicine Bow River, by A. Nelson (1257, Herbarium University of Wyoming).

South Dakota.—On *Comandra pallida:* Iroquois, by F. A. Williams (1914, Fungi Columbiani); Black Hills, near Custer, by Hedgcock and Phillips (F. P. 15827 and 15828).

North Dakota.—On *Comandra pallida:* Beaver Lake, by J. F. Brenckle (78, Fungi Dakotenses).

Colorado.—On *Comandra pallida:* Boulder, by F. E. and E. S. Clements (542, Cryptogamæ Formationum Coloradensium); south of Yuma, by H. L. Shantz, U. S. Dept. Agr. Plant-Disease Survey; Short Creek, Custer County, by T. D. A. Cockerell (99 and 104, Ellis Collection in Herbarium New York Botanical Garden); Soldier Canyon, by J. H. Cowen (168, Ellis Collection); La Veta, by C. A. Crandall (283, Ellis Collection); Pagosa Peak, by C. F. Baker (22, Plants of Southern Colorado); also by F. S. Earle (120, Herbarium New York Botanical Garden); Sangre de Cristo Mountains near Westcliffe, by Hedgcock (F. P. 8082); Steamboat Springs, by Hedgcock (F. P. 3873 and 3889); Monument, by Hedgcock (F. P. 3792, 3839, 15948, and 15950); Palmer Lake, by Hedgcock and Bethel (F. P. 3794 and 3819); Boulder, by Hedgcock (F. P. 15885); Golden, by Hedgcock (F. P. 15888); Palmer Lake, by Hedgcock (F. P. 15907 and 15948); Monument Nursery, by Hedgcock and Pierce (F. P. 15950).

Utah.—On *Comandra pallida:* Locality not given, by M. E. Jones (Herbarium New York Botanical Garden).

Montana.—On *Comandra pallida:* Helena, by F. D. Kelsey; Sandcoulee, by F. D. Kelsey (2419, Ellis and Everhart, North American Fungi); Sandcoulee (80, Montana Flora) and Helena (61, Parasitic Fungi Montana), by F. W. Anderson; Missoula, by Hedgcock and Kirkwood (F. P. 8021).

Washington.—On *Comandra pallida:* West Klickitat County, by W. W. Suksdorf (176, Flora of Washington).

California.—On *Comandra umbellata:* Shasta Springs, by W. C. Blasdale (6 North American Uredinales), by M. A. Howe (101, Fungi California), Herbarium New York Botanical Gardens; Mills Ranch, Siskiyou County, by Boyce (F. P. 15796); Integral Mine, Shasta County, by Boyce; Rocky Gulch, Siskiyou County, by Meinecke; Weaverville and Brown Creek, Trinity County, by Boyce; Goosenest Mountain, Siskiyou County, by Boyce and Rider.

DISSEMINATION OF THE FUNGUS.

Cronartium pyriforme is disseminated by means of its three spore forms—viz., æciospores, urediniospores, and teliospores—each form playing an important rôle in maintaining the succession of generations between pine trees and Comandra plants. The process of infection with this species of rust does not differ materially from that of the white-pine blister rust (12).

The æcia on the table mountain pine (*Pinus pungens*) in Pennsylvania mature from the middle of May to the latter part of June. Farther north on the jack pine (*Pinus divaricata*) they bear their spores somewhat later in the season. On the lodgepole pine (*Pinus contorta*) and the western yellow pine (*Pinus ponderosa*) from Colorado to Wyoming, the period of maturity is from the middle of June to the middle of July. In each region they develop earlier on slopes of southern exposure and at lower altitudes.

The æciospores are discharged in great abundance for a day or two and with lessened abundance for about a week longer. They infect any Comandra plants with which they come in contact. The leaves are most commonly infected, but occasionally the stems and floral parts are attacked. The infection near diseased pine is usually very abundant, decreasing rapidly as the distance increases. An abundant infection from æciospores has not been noted for more than 200 feet from the æcial center, when it is located on small pines. When large pines are diseased in the upper limbs, the distance that the æciospores are blown is greatly increased, and the zone of infection is therefore extended very much, and on mountain slopes may reach the distance of nearly 1,000 feet. This inoculation of Comandra plants by æciospores may well be designated as a primary infection, and that by urediniospores, described in the following paragraph, as a secondary infection.

In 8 to 10 days from the time of inoculation by æciospores the uredinia appear on the leaves of the infected Comandra plants and urediniospores begin to be produced. These are blown about by winds and inoculate other Comandra plants. This secondary infection greatly extends the area of diseased plants. A second crop of uredinia develops in from 8 to 10 days from these secondary infections. This process continues throughout the growing season. It is possible that as many as six or more generations of uredinia may be thus produced in one season, and the fungus may spread several miles in this manner. It is by this method of infection that the fungus spreads the greatest distance in nature, which explains why the form of fungus on the Comandra plants is more common than on the form of pines.

In about 15 days the telial columns develop from the uredinial sori on the Comandra plants. As each column grows older it gradually elongates, and the development of teliospores progresses outward

along the column with its growth. The period of teliospore formation for each telium is from one to two weeks. The teliospores germinate in situ as fast as they mature, without being detached from the telial columns. As each teliospore germinates it develops a basidium, which when typical bears four sporidia. The sporidia borne on each basidium, however, are usually less than four. The sporidia become detached as soon as mature and are carried away by even the slightest breeze. They readily infect the younger part of pine trees, thus completing the life cycle of the fungus. From observation it appears probable that germinating sporidia usually gain entrance into the tissues of the pines through wounds or in wound callus where young cells are exposed. Inoculations with another species, *Cronartium cerebrum*, on pine trees (*Pinus virginiana*) without wounds have failed, while at the same time, other conditions being similar, they were successful in wounds.

Since each generation of uredinia on Comandra plants is followed within a few days by one of the telia, there is a continual production of sporidia from the time the telia first appear till the end of the growing season. This greatly extends the period of possible infection for pines, a period which must be from two to four months, depending upon the length of the growing season in pines, which varies not only at different altitudes and in different latitudes, but also from season to season.

It is highly probable that the various spore forms of this fungus, especially the æciospores from the pines, may be carried about on the bodies of birds and of the smaller animals. In this manner they could be carried even to greater distances than is possible by wind dissemination.

If young pines in nurseries should become infected, the danger of a much wider dissemination of the fungus than has already taken place in nature is at once possible, with man as the agent. Under conditions such as occur in many localities both in the eastern and the western United States it would be easily possible for the pines in nurseries to become badly infected, owing to the abundance of Comandra plants in the vicinity.

EFFECT OF THE FUNGUS ON ITS HOST PLANTS.

EFFECT OF THE ÆCIAL FORM ON PINES.

The immediate effect of the æcial form, *Peridermium pyriforme*, varies in different species of pines and on the same species under different conditions. When young lodgepole pines or western yellow pines are attacked, either on the trunk or limbs, there commonly develops a slightly swollen area in the region of the infection. If the infected area encircles the trunk, as it usually does, a spindle-shaped or fusiform swelling may result (Pl. II, fig. 3), which varies

from an inch to more than a foot in length. In case of *Pinus pungens* (Pl. II, figs. 1 and 2), fusiform swellings are not so common as in case of *Pinus contorta* and *Pinus ponderosa*. Swelling is commonly not very evident in very young trees of any of these three species. The bark layers are usually thickened in the portions where the rust mycelium is present. So far as can be ascertained from field observations the æcia may not appear until three or more years after infection takes place.

The development of the peridia at the maturity of the æcia ruptures the bark of the diseased areas, forming numerous openings (Pl. II, fig. 2) which reach to the inner layers of the cambium. As a result the death of the cambium layer may take place, due apparently to excessive evaporation of water through the lesions. The part of the tree attacked usually is either girdled and killed outright or it is partially girdled and a canker is formed. Young pines are very commonly girdled and killed during the same season the æcia are produced. In its effect on pines, *Peridermium pyriforme* must be classed with *P. strobi* and *P. filamentosum* and be ranked as one of the most destructive species of Peridermium in North America.

In a region adjacent to Greenwood Furnace, Huntingdon County, Pa., the senior writer, during June, 1914, took notes on the number and condition of pines (*Pinus pungens*) diseased with *Peridermium pyriforme*. Again, in autumn, the condition of the same trees was noted, and it was found that of 50 diseased pines upon which the æcia had been found in June, 29 (58 per cent) were dead from the girdling effect of the fungus.

These had apparently died shortly after the æcia fruited, as dead leaves were still clinging to the branches of the trees. The pines examined were small, varying in height from 4 to 10 feet, and in diameter at the ground from 1 to 4 inches. A similar effect was noted during the autumn of 1914 on a smaller number of young pines (*Pinus ponderosa*) in the Black Hills near Custer, S. Dak.

J. S. Boyce, of the Office of Investigations in Forest Pathology, has reported this fungus on the yellow pine (*Pinus ponderosa*) in Klamath, Shasta, and Trinity National Forests in California.[1] This report states that in the Klamath National Forest—

> The parasite produced spindle-shaped swellings at the point of infection on the yellow pine, usually on the main stem but occasionally on the branches. These swellings varied from 2 inches to a foot in length.
>
> The fungus on yellow pine undoubtedly kills that portion of the main stem or branch of the tree above the point of infection. A number of small trees were found to have been killed. Each of these bore one or more spindle-shaped swellings on the stem. A volunteer (shoot) had then appeared while a new infection had occurred just below the point where the volunteer joined the main stem. A repeated killing of this kind causes a strikingly deformed tree.

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[1] Boyce, J. S. Notes on *Cronartium pyriforme*. Unpublished report submitted December 7, 1914.

The largest infected tree found was 12 feet high and 3 inches in diameter at breast height, approximately 22 years old, with the infection occurring 5 feet from the ground. In another area here 10 saplings killed by the fungus, with only one living uninfected tree, were found.

One diseased area of *Pinus ponderosa* at Mills Ranch on the north slope of Goosenest Mountain in the Klamath National Forest was described by Boyce, which contained at least a hundred acres. The largest tree diseased by the fungus in this area was 8 inches in diameter at breast height. Spindle-shaped swellings were common, but more especially on the younger, smaller trees. The girdling effect and death of the host tree in the parts above the point of infection were very much in evidence in this area. Small trees apparently were girdled and killed much sooner than older trees. Wounds caused by some gnawing animal, presumably the porcupine, were common on trees in areas where the fungous disease occurred. In one of the diseased portions of the forest a sample plat was established by Boyce and a count of the healthy, infected, dead, and dying trees of *Pinus ponderosa* was made. The result was as follows: Out of 314 trees in the plat, 153 (48.7 per cent) were apparently healthy, 52 (16.5 per cent) were plainly diseased by the fungus, 3 (0.9 per cent) were dying, and 106 (33.7 per cent) were dead from the effects of the fungus. In the words of the report:

Over 50 per cent of the total number of trees of the sample plat had been infected, and nearly two-thirds of the total number infected had already been killed. There is, of course, a possibility that the death of some of these might have resulted from other causes, but only those trees were included which I was certain in my mind had been killed by the fungus.

Boyce's data corroborate those taken by the senior writer both in Pennsylvania and South Dakota.

Reporting concerning an area of diseased *Pinus ponderosa* along Browns Creek in Trinity National Forest, Boyce says:

There were many dead trees, undoubtedly killed by the fungus, with spindle-shaped swellings on the main stems. On living infected trees the æcia were sporulating (June 27, 1914), but not very abundantly, not to be compared with the sporulation found at Rocky Gulch on May 20. One infected sapling was found in which the major portion of the bark had been destroyed either by wood rats or porcupines.

Where the trunk is not girdled, cankers or catfaces are occasionally formed by the death of a portion of the cambium. In such cases the continued presence of the fungus in the live tissues beyond the dead area stimulates their growth, and the fungus may fruit a number of times before the tree is killed. Catfaces on the lodgepole pine (*Pinus contorta*) and on the western yellow pine (*Pinus ponderosa*), however, are more commonly produced by another species of rust, *Peridermium harknessii.*

Peridermium pyriforme, when it infects the trunk of a pine tree, may spread from the trunk to such limbs as spring from a point near

the center of infection or, vice versa, may spread from the point of infection on a limb to that part of the trunk adjacent to the diseased area on the limb. In this it resembles *P. filamentosum* (5) and the fusiform type of *P. cerebrum* (*P. fusiforme*) (7, p. 248). Such instances in the case of both *P. pyriforme* and *P. filamentosum* on *Pinus ponderosa* have been observed by the senior writer in Colorado and Wyoming and noted by Spaulding (11, p. 28, 34) in the case of *Peridermium strobi* on white pines in the northeastern United States.

EFFECT OF THE UREDINIAL AND TELIAL FORMS ON COMANDRA PLANTS.

The effect of the uredinial and telial forms of the fungus, *Cronartium pyriforme*, on Comandra plants can not be separated into two distinct sets of symptoms, since the two forms are produced on the same area of tissue, the one following the other in a few days. Both the uredinia or the telia may occur on either surface of the leaves, as well as on the younger portions of the stems, and occasionally on the floral parts.[1] In badly infected plants there is a decided shortening of both the stems and the leaves in their growth, so much so as to change the entire aspect of the plants. This is usually accompanied by a slight chlorosis of the leaves. Where the infection is slight, the diseased spots on the leaves are usually a lighter green color than the uninfected portions. Late in the growing season the reverse coloration sometimes takes place, and the chlorophyll is retained longest in light-green areas in the leaves where the mycelium of the fungus is found, even after the remainder of the leaf has become yellow from fall coloration.

In badly infected Comandra plants defoliation takes place prematurely; that is, before drought, frost, or cold weather bring it about. No data have been obtained as to the final effect of the rust on Comandra plants. The effect, however, is decidedly stunting, and plants infected badly for several seasons would undoubtedly be killed.

ERADICATION AND CONTROL OF THE FUNGUS.

One of the most serious facts in connection with the prevalence of *Peridermium pyriforme* in some portions of the western United States is the danger of introducing it into localities now free from it through the shipment of trees in the work of artificial reforestation. For this purpose nursery stock is often shipped long distances. The forest nursery if situated in mountain regions is apt to be in a locality where Comandra plants are common. Since these serve as host plants for both the uredinial and telial forms of the fungus, their presence may lead directly to the infection of the young pines in the nursery and indirectly to the infection of localities hitherto free from the disease.

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[1] In *Comandra pallida* this is the case. In *Comandra umbellata* the uredinia and telia are found uniformly on the under surface of the leaves.

If it were possible to distinguish all of the diseased trees at the time of planting, it would be an easy matter to discard them and thus prevent the further spread of the disease. Such, however, is not the case, since the disease may not become evident until three or four years after the young trees are infected and until after they are planted in the forest. This being the case, other means for the control of the disease must be adopted. The most feasible plan to prevent further infection in the nursery and the subsequent dissemination of the disease through infected nursery stock appears to be the elimination of all Comandra plants in the vicinity of the nursery.

In order to protect the nursery from infection whenever the disease is present in adjacent forests, all diseased pines that can be found within a radius of at least half a mile from the nursery should be cut down. These can be selected most easily by a person familiar with the fungus, at the time the æcia mature in the pines. As previously stated, this period varies from the middle of May till in August, depending upon both the latitude and the altitude of the locality. This cutting-out process should be repeated each year until no more diseased trees can be found in the proposed neutral zone.

The elimination of all diseased pines will not suffice, however, absolutely to control the disease in the nursery when Comandra plants are in the vicinity, since it is quite certain that the fungus can spread by the urediniospores from one Comandra plant to another for long distances in one season. By this means the disease could be carried from diseased pines outside of the neutral zone or belt of removal to the young pines in the nursery. To protect the nursery against infection from this fungus all Comandra plants within 1,000 feet of the outer boundaries of the nursery should be removed by digging them out.

Comandra plants are herbaceous perennials and spread primarily by means of seeds and secondarily by means of underground runners. The secondary method is the more common. The seeds, being edible, are much liked by birds and rodents, and it is possible that they may be carried by these animals to a considerable distance from the original place of growth, thus starting new plant colonies. The eradication of Comandra plant colonies will be difficult, owing to the numerous underground runners, any of which are liable to be broken off and left in the ground to start new plants. It will no doubt be necessary to dig up the plants repeatedly before they can be completely eradicated. All species of Comandra are parasitic and derive part of their food supply from other plants by a direct attachment of the smaller side roots of Comandra to the roots of the host plants. It is not yet known how many species of plants are thus parasitized, but several widely different species are attacked. Species of Vac-

cinium are commonly parasitized. This subject is now being investigated by the writers.

The recommendations here given are based on observations made in forests by the senior writer and not on actual experiments. An attempt to control this disease as recommended here has been planned and will probably be carried out in 1915. Until it is certain that the neighborhood of a nursery is free from this fungus, shipment of stock to uninfected forests should be avoided.

The spraying of pines with Bordeaux mixture or other fungicides for the prevention of infection by *Cronartium pyriforme* can not be recommended until it is known that this method is effectual in controlling the disease.

The spraying of Comandra plants with a poisonous substance to kill the foliage and tender shoots at the time they might be infected from the æcial form of the fungus on pines should prevent the immediate spread of the disease to the pines in adjacent nurseries. This spraying should be done as soon as the leaves of the Comandra plants are fully developed and before the plants bloom. This would probably be from the latter part of May to the middle of July, depending on the altitude and the latitude of the locality. Should the Comandra plants send forth new growth later in the season it might be necessary to spray a second time. Spraying should be repeated each year as long as any Comandra plants remain alive. Where young pines are present, this method could not be used without killing them, and the uprooting of the Comandra plants is recommended for such areas.

Mr. H. R. Cox, Agriculturist of the Office of Farm Management, Bureau of Plant Industry, has prepared a circular letter giving directions for the use of plant poisons in killing vegetation. This circular follows, more complete directions being obtainable from the office mentioned upon request:

For several years this office has been making tests of various chemical plant poisons for killing all vegetation in such situations as driveways, pathways, tennis courts, railroad rights of way, and similar places. It appears that of the substances there are three that are better than any of the rest, namely, arsenite of soda, common salt, and some form of petroleum. The best one of these for each case will depend upon conditions. It seems to be more economical usually to make a number of comparatively light applications for the purpose primarily of killing the foliage rather than one heavy one to affect the roots as well as the tops.

In the case of most kinds of vegetation excepting the grasses, and especially for vegetation of a broad-leafed character, arsenite of soda is highly effective. The commercial grade may be obtained at about 25 cents per pound from some of the wholesale chemists. If large areas are to be treated, it can be made at home more cheaply by boiling 1 pound of white arsenic and 2 pounds of sal soda in a gallon of water until a stock solution is formed. From 10 to 20 pounds of the commercial arsenite of soda or from 7 to 14 pounds of the white arsenic in the home-mixed formula, either one diluted to make from 50 to 100 gallons of solution, is sufficient to kill most of the foliage on 1 acre.

Common salt may be applied dry, provided it is fine grained and is scattered very uniformly. Salt may be applied more uniformly, however, if it is made into a saturated solution (1 pound to 1½ quarts of water). The latter is usually the most satisfactory form. It should be used at the rate of from 3 to 5 tons per acre, depending upon the character and rankness of the vegetation.

Of the petroleum products, fuel oil is about the most satisfactory, although this is sometimes difficult to obtain, and then only in barrel or tank-car lots. Near the oil fields, crude oil as it comes from the well can be obtained cheaply and is quite satisfactory. The petroleum products should be applied at the rate of from 300 to 400 gallons per acre. If small areas are to be treated, so that the matter of expense is of little consideration, kerosene may be used. The petroleum products seem to be the most effective of all when applied to narrow-leafed vegetation, such as grass; salt seems to be the next in effectiveness on such plats, and arsenic third.

A spraying outfit is best for applying liquid material, excepting the salt brine, with which a sprinkling can or sprinkler will do faster work. The petroleum products are very hard on the rubber parts of spraying outfits, but it is necessary to use a sprayer in that connection on account of economy of application; with very small areas where economy is not to be considered the oils can be applied through a sprinkling can.

In the forest under our present conditions and market values it is not best to advise methods of elimination so expensive as have been given for the protection of nurseries. In badly infected areas of young forest trees, all diseased trees should be cut out whenever possible. This often can be done by the forest officer without very great expense, owing to the small size of the trees. In lumbering, trees diseased with catfaces or cankers should not be left for seed trees, as their vitality has been lowered and they will not produce as good a crop of seed as more healthy trees, and it is also highly probable that the viability of the seed produced by such trees is lower than that produced by more healthy trees. Again, trees with such cankers are often capable of producing æciospores around the border of the cankers and if allowed to remain for seed trees would become centers of infection for the younger generations of trees in the new forest.

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BULLETIN No. 248

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief.

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FLEAS.

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CONTENTS.

INTRODUCTION.

Fleas have forced themselves on man's attention for many centuries. All are familiar with these elusive little pests, knowing well their brownish color, peculiar flattened shape, apparent ability to sense the approach of danger, and the proverbial ease with which they escape. Their propensities for annoying man by inflicting bites in rapidly changing situations and for persistently worrying dogs and cats are well known.

However, it is not only in the rôle of annoyers of man or beast that fleas assume importance, for within the last decade the world has come to know fleas in their most important relationship to the welfare of mankind—that of transmitters of disease, and particularly of the dread disease known as plague. Aside from plague, which levies a death toll well into the hundreds of thousands yearly, attention is directed to fleas as important insects on account of their probable

NOTE.—The activities of fleas as carriers of bubonic plague and other diseases, as parasites upon poultry, and as pests to man and other animals are presented in this bulletin. Descriptions, life history, breeding places, hosts, and methods of eradication and control are given.

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connection with the disease of warm climates known as infantile kala-azar. There is also reason to believe that fleas play some part in transmitting leprosy. It has been found that the tapeworm of the dog, which has been known to attack man, is dependent upon some insect in which to develop one of its stages, and the dog flea often serves in this capacity. Another interesting rôle which a certain species of flea has been found to fill, though of no known direct importance to man, is the transmission of a blood parasite of the rat known scientifically as *Trypanosoma lewisi.* One kind of flea which is becoming widely distributed in the Tropics has the peculiar habit of burrowing into the flesh of man, especially around the toes. This species causes severe sores and often permanent crippling. In the United States, aside from their connection with plague transmission, we are concerned most with insects of this group as annoyers of man and animals. In the latter case the pests often become so numerous as to cause more or less loss. This is particularly true of the chicken flea, or "sticktight," which will be discussed in the following pages.

Fleas, as is generally known, are true insects. They have been thought by many entomologists to be closely related to the Diptera, or two-winged flies, but now they are usually considered to constitute a separate order of insects. Their peculiar shape,[1] flattened from side to side, and armature of spines and bristles are closely correlated with their parasitic habits, enabling them to move rapidly between the hairs or feathers of their hosts.

HOSTS OF FLEAS.

Fleas in the adult stage may be said to be parasitic exclusively on warm-blooded animals. A single exception has been recorded—that of one flea which was found attached to a land snake in Australia.

A great many species of birds and most mammals have been found to be infested by these parasites. The group of animals of which the horse, ox, and sheep are representative are probably least subject to attack. It is not the purpose to convey the idea that there are as many kinds of fleas as there are birds and animals. In fact, the number of distinct species of fleas now known is probably not greatly in excess of 400. In general, there are certain birds or animals, spoken of as hosts, upon which these insects prefer to feed.

Some species of fleas appear to have much more restricted host relationships than others; that is, they are found on comparatively fewer animals. In other instances fleas may not be found uncom-

[1] Some knowledge of the structure of a few of our common kinds of fleas may be derived from an examination of the illustrations in the following pages, which, with the exception of figure 1, were drawn by Mr. Harry B. Bradford.

monly on certain hosts, but they are not at home on these and would probably not live long or reproduce if made to feed on them exclusively. This class of hosts usually becomes infested by being closely associated with the true host of the fleas, as, for instance, in case of a rat entering a squirrel burrow or a carnivorous animal devouring a flea-infested rodent and thus getting the insects upon its body. Such hosts are usually spoken of as accidental or temporary. While infestations of this kind are seldom of importance to the host animal from the standpoint of direct injury, they may have a vital influence by transmitting disease and may also have an important bearing on control. As a result of this habit of fleas of clinging to, or temporarily feeding on, hosts which are not necessarily congenial, long lists of species of fleas accredited to a single kind of animal or bird are often found. For instance, more than 20 species of fleas have been taken on common wharf rats.

BITING HABITS.

The sensation produced by the biting of a flea is well known to most persons. The annoyance, however, is partly produced by the movements of the insect and by the mental unrest caused by the knowledge that fleas are present beneath the clothing. The effect of flea bites on man is discussed further on page 16. With very rare exceptions, adult fleas partake of no food other than the blood of warm-blooded animals, and it appears that reproduction never takes place until the fleas have partaken of such blood.

The mouth parts are well adapted to piercing the skins of their hosts and sucking up the blood. The essential piercing organ consists of three slender parts. A groove along the inner sides of two of these, the mandibles, with the closely applied third, forms a channel through which the salivary fluid is forced into the wound and through which the blood is pumped into the body. An idea of the structure of the mouth parts may be gained by referring to figure 1, *e* and *g*.

Most species are easily disturbed when feeding, and this accounts, in part at least, for the frequency with which a single flea may bite.

With the exception of the "sticktight" flea and certain of its relatives, fleas do not remain attached to their hosts for long periods. The amount of time spent off the hosts seems to vary much with the species. Normally the adults feed every day and possibly oftener, but in the case of interrupted meals, as has been mentioned, they may bite a great many times during a day, and some species, such as the cat and dog fleas, probably remain on the host almost continuously, feeding at very frequent intervals. A great many fleas are nocturnal. These

depend largely on finding a host at night, and they tend to keep secluded during the day.

In the case of inoculation of an animal with plague bacilli by a flea it has been observed that there is a relationship between the point of flea attack and the formation of the sweelings, or buboes. In this connection it is interesting to note that certain species show a marked tendency to infest certain portions of the host animal.

LIFE HISTORY.

The fleas pass through four distinct stages of development, viz, the egg, the larva, the pupa or resting stage, and the adult. All of

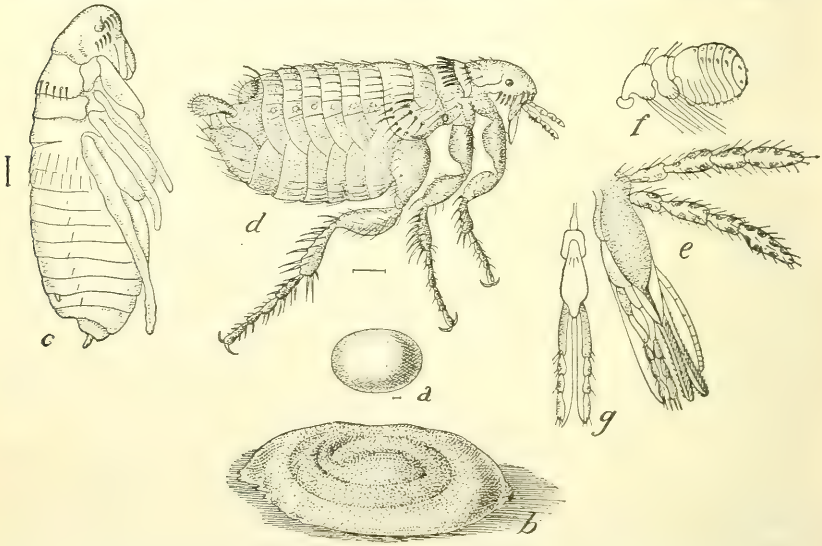

FIG. 1.—The dog flea (*Ctenocephalus canis*): *a*, Egg; *b*, larva in cocoon; *c*, pupa; *d*, adult; *e*, mouth parts of same from side; *f*, antenna; *g*, labium from below. *b*, *c*, *d*, Much enlarged; *a*, *e*, *f*, *g*, more enlarged. (From Howard.)

the different kinds of fleas resemble one another rather closely in these different stages.

THE EGG.

The eggs are ovoid in shape and white or creamy in color, some strongly reminding one of miniature china eggs. Although rather small, they are readily seen with the naked eye, especially if placed on a dark piece of cloth or paper. (Fig. 1, *a*.) They are formed after the female has been feeding on a host for a few days and are usually deposited while the flea is on the host, but are not glued to the hairs or feathers, as is the case with lice and some other insects. The human flea probably deposits most of its eggs while free from the host. The eggs usually fall from the animals in their nests; hence

there is a tendency for the young and, of course, the resulting adults to concentrate in the vicinity of the sleeping places and most frequented haunts of the host. This serves the fleas in three ways: (1) By giving them the protection of the bed of the animal in which to develop; (2) by furnishing food to the young in the form of partly digested blood excreted by the adults while on the host; (3) by keeping these parasites concentrated where they can easily secure access to the host when they become mature. This habit is also important when we attempt to control the fleas and is referred to again under that topic (pp. 25–28).

The number of eggs deposited by a single female and the rate of deposition undoubtedly vary largely with the species, the abundance of food, and climatic conditions. Prof. Bacot, of the Lister Institute, London, in his extensive studies of fleas has conducted a number of experiments bearing on this point. The number of eggs deposited daily is small, but deposition may continue for many weeks. Bacot records 448 eggs as the greatest number observed by him to have been deposited by a single female of the human flea. In some of these experiments he found that the female would continue to deposit eggs for a period of over three months.

THE LARVA.

Within from 2 to 12 days, depending on temperature and moisture conditions, the eggs hatch into minute, whitish, legless, and eyeless maggots. These are not parasitic, but move about actively in the dust and débris in or near the nest of the host. Under favorable conditions the growth of the larvæ is rather rapid. Flea larvæ usually molt twice. The larvæ of the dog flea may molt three times, according to observations made by Mr. Theodore Pergande, of the Bureau of Entomology. The first molt takes place in from 2 to 7 days after hatching, the second from 2 to 6 days later, and the third about 5 days after the second. The shortest larval period observed in these experiments was 7 days. In England Mr. Bacot found that the larval period in the dog flea ranged from 11 to 142 days; in the human flea, from 9 to 102 days; in the European rat flea, from 15 to 114 days; and in the Indian rat flea, from 12 to 84 days. Food, humidity, and temperature are all important factors in influencing the rapidity of development. The larvæ, or maggots, are slender, and each joint is provided with a number of hairs or bristles which assist it in crawling. The head differs slightly in appearance from the other segments and bears some of the usual head appendages with which most insects are supplied. These include short, stout antennæ, or feelers, and a pair of mandibles fitted for biting. The top of the abdomen is provided with two fleshy fingers which aid the larva in its movements,

and a comb of fine hairs. When full grown the maggots are usually less than one-fifth of an inch in length. The larva of a common species is illustrated in figure 3 (p. 14).

The food of the larvæ appears to vary somewhat with the species, since some seem to thrive on a considerable variety of foods, while others are more restricted in their diet. In nearly all species it seems certain that the partially digested blood voided by the adult flea in feeding constitutes an important part of the diet of larvæ, especially when newly hatched. The remainder of the food consists of particles of organic matter, either of animal or vegetable origin, which are found in the cracks of floors, in the nests of the host, or even mingled with the sand near the habitations of the host.

THE COCOON AND PUPA.

When the larvæ have attained full size they spin cocoons of more or less oval shape (fig. 1, *b;* fig. 4). These vary from almost white to brownish, but owing to the particles of sand and dust usually attached the color is often dark. The insect in this stage thus is rendered inconspicuous. In structure the cocoons range from rather light, flimsy silken coverings to very thick tough or even thick brittle encasements. Within the cocoon the larva molts its skin and enters the pupal, or resting, stage (fig. 1, *c*), which somewhat resembles the adult insect. At first the pupa is very pale in color, but it gradually darkens as the time for the appearance of the adult approaches. The length of time spent in the cocoon varies with climatic conditions. At Washington, D. C., Mr. Pergande found that the dog flea would emerge as an adult within from 7 to 9 days after spinning the cocoon. In his experiments in England Mr. Bacot found the period from spinning of cocoons to the emergence of adults to range as follows: European rat flea, from 8 days to over a year; human flea, from 7 to 239 days; dog flea, from 7 to 354 days; and Indian rat flea, from 7 to 182 days.

In these experiments Mr. Bacot found that the period within the cocoon varied markedly with the temperature. This was particularly true with the Indian rat flea, which had its cocoon stage greatly lengthened when the daily mean temperature fell below 65° F. These long resting periods were generally not produced in the case of the human flea until the mean temperature fell to 50° F., and to 40° or 45° F. with the European rat flea. The work of this investigator suggests that the winter is passed in this stage, and that fleas may thus tide over dry hot periods. It is certain that the cocoon offers much protection from adverse weather conditions. The larva may remain quiescent for long periods within the cocoon before actually pupating, and another resting period may occur within the cocoon after the

insect has become adult. Observations made in India and in our own country in the vicinity of San Francisco show that there is no complete cessation of activities in the winter. This is also true as observed in several species by Mr. A. H. Jennings, of the Bureau of Entomology, while in Panama, and the author has observed considerable numbers of fleas on hosts in the Southern States in midwinter. These included the dog flea and the chicken flea, or "sticktight," as it is colloquially known.

LIFE CYCLE.

The total period from the deposition of the egg to the emergence of the adult, in tests with the dog flea conducted during the summer time at Washington, ranged from 17 to 35 days. The length of the different stages and total life cycle of some of the common species of fleas may be shown best by presenting a table compiled by Mitzmain from the works of various authors, and amplified to include recently published results.

TABLE I.—*Life cycle of fleas in different countries.*

Country and species of flea.	Length of egg stage.	Length of larval stage.	Length of cocoon stage.	Length of complete cycle.
United States:				
Atlantic coast—	*Days.*	*Days.*	*Days.*	*Weeks.*
Dog flea (*Ct. canis*)	2 to 4	8 to 24	5 to 7	2 to 4
Pacific coast—				
Human flea (*P. irritans*)	7 to 9	28 to 32	30 to 34	9 to 11
European rat flea (*C. fasciatus*)	5 to 6	4 to 7	24 to 26	7 to 8
Indian rat flea (*X. cheopis*)	9 to 13	32 to 34	25 to 30	9 to 11
Ground squirrel flea (*C. acutus*)	7 to 8	26 to 28	24 to 27	8 to 9
Europe:				*Days.*
Human flea	4 to 12	8 to 100	6 to 220	19 to 264
Dog flea	8 to 14	12 to 142	10 to 354	35 to 366
European rat flea	5 to 14	12 to 114	3 to 450	20 to 467
Indian rat flea	10 or less	14 to 84	9 to 191	31 to 256
Bird flea (*C. gallinae*)	7 or less	13 to 50	6 to 70+	26 to 127
India:				
Indian rat flea	2	7	7 to 14	21 to 22
Australia:				*Weeks.*
Human flea	6	12	14	4 to 6

LENGTH OF LIFE OF THE ADULT.

Food is the most important single factor in longevity of the flea. Comparatively cool, humid weather greatly lengthens life. Moderately warm, moist weather is more favorable than cool weather for egg laying, but shortens the total life period. Hot, dry weather soon proves fatal to the adult. In connection with this subject reference is made to the work of Mr. Bacot in England, as he has conducted the most complete set of experiments yet published to determine adult longevity. When the temperature registered from 45 to 50° F. and the air was nearly saturated with moisture, this investigator found that specimens of the human flea lived for 125 days, the European rat

flea 95 days and the dog flea 58 days, the Indian rat flea 38 days, and a species of bird or chicken flea (*Ceratophyllus gallinae*) 127 days. These records were made with individuals which received no food whatever. When kept in a box and fed at frequent intervals, he found the human flea to live for more than 513 days. The European rat flea lived 106 days, the dog flea 234 days, the Indian rat flea fed on man 100 days, and the above-mentioned chicken flea 345 days.

In Texas the author has observed the "sticktight," or chicken flea, to live for several weeks attached to a host, but the greatest possible longevity has not been determined.

In experiments conducted in California Mitzmain had specimens of the European rat flea alive for 160 days when fed frequently, the Indian rat flea for 49 days, and the common ground-squirrel flea (*Ceratophyllus acutus*) more than 64 days.

In India and California the longevity with unfed fleas was found to be much shorter than is indicated by the records made in England. Usually the maximum longevity of unfed rat fleas in these warmer climates is but a few days.

Experiments made by Mr. C. Strickland in England, and some conducted by the author in Texas, indicate that the presence of rubbish, dust, or sand, in which the adults may secrete themselves, is an important factor in increasing longevity of unfed fleas. This is especially true during hot, dry weather.

BREEDING PLACES.

In addition to having suitable hosts upon which the adult fleas may feed and thus produce eggs, it is essential that the eggs, the maggots which hatch from them, and the pupæ which finally again produce adults have favorable conditions for development. In houses these conditions are usually found in the cracks of the floors or under matting or carpets. Rat fleas often breed in numbers in granaries, barns, warehouses, and basements, particularly when these are not in constant use or when gunnysacks and rubbish are allowed to accumulate in such places. The immature stages of "sticktight" fleas breed mainly in buildings, such as chicken houses, barns, and sheds which are inhabited by the principal hosts.

Dirt floors in chicken houses or sheds seem to be more favorable than wooden floors for flea development. The young fleas may be found amongst the partially dried excrement, straw, feathers, and other waste in such situations. Fleas have been found also to reproduce in great numbers under corncribs and buildings where dogs sleep or chickens go during the heat of the day. Here the maggots are intermingled with and feed upon the animal and vegetable matter which has accumulated on the soil.

Occasionally fleas, particularly the human flea and dog flea, may breed out of doors. Mr. D. L. Van Dine has recorded an instance in Hawaii where a lawn was infested with the dog flea, and instances are known in the United States of this flea and the human flea breeding in protected situations, as under shrubbery or in the shade of buildings in sand which contains a considerable amount of animal or vegetable matter.

In nearly all cases the breeding places are very closely associated with the haunts or resting places of the host. Instances where adult fleas get upon man well away from such haunts must usually be considered as being the result of the adult fleas having become detached from a host rather than by the fleas having been reared in such situations.

FACTORS INFLUENCING FLEA ABUNDANCE.

Everyone familiar with the flea knows that there is marked seasonal variation in abundance and often distinct variation from year to year. As has been stated, fleas continue to breed throughout the year in California and in parts of our Southern States. This is even more marked in India, Panama, and other tropical countries. The human flea and dog flea are seldom found to worry man during the winter months. This is explained by a falling off in the rapidity of breeding, the comparative inactivity of the adult fleas, and, as Mr. Mitzmain has shown, the tendency for the human flea to remain largely on the lower animals during winter. Throughout the United States the fleas which attack man are most prevalent during the summer months. In India there is a marked decrease in numbers with the oncoming of the hot, dry season. This was particularly noticeable in the case of the European rat flea, which, according to observations of the Indian Plague Commission, began to disappear early in April, and from May 15 to the beginning of November not a single specimen was seen.

The variation from year to year is no doubt principally due to weather conditions. Dr. Howard states that he believes the years of greatest flea abundance are those in which the summer rainfall is above normal. No doubt humid summers, even though the rainfall were not abundant, would produce the same results. These statements are borne out by the effects of dry conditions on the various stages of fleas as observed by several investigators.

Although fleas of one kind or another are to be found all over the United States, there are certain regions where one or more species are especially abundant. In general, in those portions of the country where mild winters and comparatively humid summer atmospheric conditions are the rule fleas are found most prevalent. The amount of rainfall is also a factor in this regional abundance. While

extreme drought is detrimental to reproduction of fleas, excessive rainfall also has a restraining influence. These conditions influencing flea abundance are dependent to some extent on the character of the soil and the presence of hosts and breeding places. Sandy soil is best fitted for flea breeding, as drainage is facilitated and the surface is not so apt to become dried out as on many other soils. In other words, it provides more uniform moisture conditions. It is also probable that sandy soil is of some benefit to the flea by offering more protection to the adult insect.

The local abundance of fleas is, of course, dependent upon factors mentioned in the preceding paragraphs, but in addition the abundance of hosts, their relationship to one another, and the presence of breeding places are of much importance. The abundance of rats in seaports is often responsible for a large flea population, and the continued destruction of the rodents often correspondingly reduces the number of fleas. As has been explained, fleas often feed on several different animals, and when these animals associate they each contribute to the breeding of fleas. An example of this occurs in the instance of the chicken flea, or "sticktight." This flea feeds in great numbers on dogs and cats, and when these animals sleep in and around chicken yards they and their beds are often the source of great numbers of fleas which attack the poultry. Another instance of the effect of the association of hosts and presence of breeding places for fleas may be given. Often untold numbers of fleas may continually infest houses and annoy the inhabitants as a result of hogs, dogs, or other animals being allowed to go beneath the house to make their beds.

THE JUMPING OF FLEAS AND OTHER MEANS OF SPREAD.

The question of the distance a flea can jump, especially in a vertical direction, is important in considering isolation of man or animals from them. The jumping powers of fleas are exaggerated in the minds of most people. The human flea is probably the strongest jumper. Mitzmain, working in California, found the maximum horizontal distance this species could jump was 13 inches. He found a few specimens could jump to a height of 7¾ inches. Five inches has been recorded as the maximum horizontal jump of the Indian rat flea by the Indian Plague Commission, and in experiments conducted by Mitzmain 3½ inches was the greatest height to which this species could jump. In other tests investigators found that the European rat flea and common ground-squirrel flea (*Ceratophyllus acutus*) could jump slightly less than 3½ inches in a vertical direction. Observations of the writer on the sticktight flea indicate that its jumping power is almost nil. The legs of this species are comparatively

small, not being developed for jumping like those of the human flea and other species.

Nearly all fleas have more or less difficulty in crawling on smooth surfaces or on clothing, yet in time they are capable of making considerable progress on clothing, either in a vertical or a horizontal direction.

The movements of the fleas themselves are of little direct importance in spreading the species. Their jumping powers, however, aid them in finding hosts and securing attachment thereto, and upon the hosts, whether normal or temporary, they may be carried considerable distances. The species are further disseminated by the scattering of eggs as an infested host goes from one place to another and by the dislodgment of the females from the host. Since the fleas leave a dead animal, in this way adults are scattered, and in some instances they may be infected with the disease from which the host died. The greatest spread of fleas is no doubt brought about through the transportation of infested animals from one place to another through the agency of man. In this way rat fleas may be carried between ports in all quarters of the globe on rat-infested ships. Chicken fleas and dog and cat fleas may also be shipped long distances on infested hosts. It is also possible to spread fleas in merchandise, either in the adult or immature stages. Consideration of these points is of much importance in preventing the spread of plague from one locality to others.

FLEAS AS CARRIERS OF DISEASE.

BUBONIC PLAGUE.

Although the dread disease of man known as bubonic plague has occurred in the United States, the most important outbreak being in San Francisco during the last few years, fortunately it was restricted closely to the portions of the country where it was introduced.

The earliest records of the disease connect the outbreaks in the human family with death among rats. At the present time the disease is considered to be essentially a disease of rats. Man and other animals become infected through the agency of fleas as a result of these epizootics among rats.

The malady has a history dating far back in Biblical times. Probably the worst outbreak known began in the eleventh century and culminated in the fourteenth. During this period practically the entire Eastern Hemisphere was swept, and the number of deaths due to the "black death," as it was known in parts of Europe, was appalling. Within the last 18 years this malady has caused the death of over 7,000,000 in various parts of the world. During the last decade the disease has broken out in various parts of Africa, Europe, Australia, Japan, South America, West Indies, and in the United States.

As a result of international regulations, including quarantines, and owing to the work of the Public Health Service, the disease has not assumed serious proportions in this country. Although the malady has persisted for some time among rats and ground squirrels in and near San Francisco, very few human cases have developed, and the malady has been entirely stamped out in that vicinity. The occurrence of plague in New Orleans during 1914 caused some excitement, but by prompt action by the State and Federal authorities the outbreak has been limited to that city and the number of human cases has been small. In India, China, and a number of other countries the disease is still present in epidemic form, despite the work of the Indian Plague Commission and other organizations for the furtherance of control work. Marked progress is being made, however, and the ultimate stamping out of the pestilence may be expected.

As has been stated, the flea is the medium by which the disease is spread from rats and ground squirrels to man. These insects also act as carriers from rat to rat. That the flea is responsible for the transmission of plague has been determined within the last two decades as a result of studies conducted by a number of investigators in various parts of the world. The importance of an accurate knowledge of these insects in this connection is apparent to all. It has been determined by the Plague Commission of India and other investigators that several species of fleas may serve as vectors of plague. Those which are commonly found on rats and ground squirrels and which may carry plague under certain conditions include the following species:

The Indian rat flea (*Xenopsylla cheopis* Roth.).

The European rat flea (*Ceratophyllus fasciatus* Bosc.).

The human flea (*Pulex irritans* L.).

The European mouse flea (*Leptopsylla musculi* Dugès).

The dog flea (*Ctenocephalus canis* Curtis).

The squirrel fleas (*Hoplopsyllus anomalus* Baker and *Ceratophyllus acutus* Baker).

The cat flea (*Ctenocephalus felis* Bouché).

The rat fleas *Ceratophyllus anisus* Roth. and *Pygiopsylla ahalae* Roth.

The former of the last two mentioned occurs in the East Indies, where it has been shown to be capable of carrying plague, and the latter takes the place of the European rat flea in China and Japan. All of these species, with the exception of the last two named, are found in the United States.

The very severe outbreak of plague in Manchuria a few years ago is thought by many to have started among trappers of the "tarbagan," or groundhog, as a result of having been bitten by the flea, *Ceratophyllus silantiewi* Wagner, which is abundant on this animal.

The Indian rat flea has been found to be by far the most important in plague transmission in India, and this species is now widely distributed throughout the Tropics and in seaports which have direct trade with the Orient. At the present time this species is abundant in parts of the seaport cities on the Pacific and Gulf coasts of the United States. Away from the water front its place as a rat parasite is largely taken by the European rat flea (*C. fasciatus* Bosc.) and the mouse flea (*Leptopsylla musculi* Dugès). The

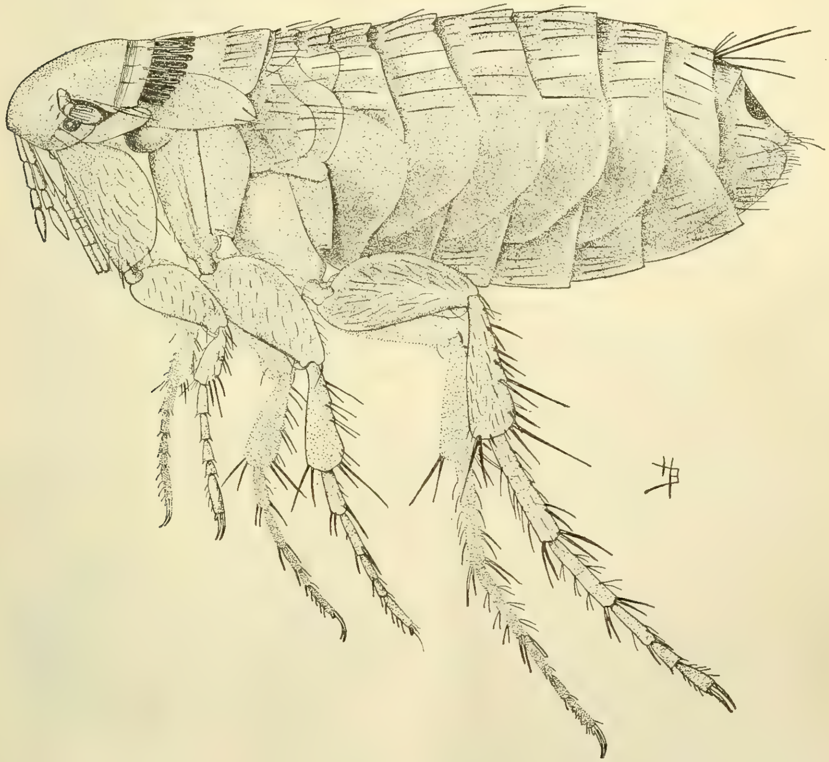

FIG. 2.—The European rat flea (*Ceratophyllus fasciatus*) : Adult female. Greatly enlarged. (Original.)

human flea is common in many parts of the country, and the squirrel fleas mentioned are abundant on ground squirrels (*Citellus beecheyi*) in the western part of the United States. All of these fleas have been found to bite man and will feed on rats. The adult European rat flea is illustrated in figure 2, the larva of this species in figure 3, and the cocoon in figure 4.

As has been stated, plague always occurs among the rodent population before any number of cases develop in man. The rats in a plague-free community usually receive their initial infection from a diseased rat which has been imported from some plague center. This,

together with the favorable conditions as regards rats and fleas in seaports, accounts for the fact that the disease usually first breaks out in such places. The pestilence, when once introduced, is carried rapidly from rat to rat by the fleas. This spread is increased by the fact that most of the fleas leave the rats as they die and pass to others. It is these fleas, set free by the death of their plague-stricken hosts, which form the chief menace to man.

The method by which fleas convey plague germs has received considerable attention, and various theories have been advanced from time to time in an effort to explain the mechanism of transmission. It appears that the two most important methods are by contamination of the skin of man or other host by excrement voided by the infected fleas while feeding and the subsequent rubbing or scratching in of the germ-laden material and by the injection of the disease organism into the wound made by the flea at the time of feeding. Researches made by Mr. A. W. Bacot, of the Lister Institute, have proven this last method to be an important one. He showed that the entrance to the stomach of some of the fleas becomes plugged by a growth of the plague germs. This ultimately prevents the passage of food backward into the stomach, but does not prevent the flea from sucking up small quantities of blood, some of which is forced back into the wound after becoming laden with the disease organism.

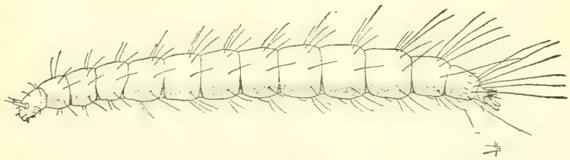

FIG. 3.—The European rat flea: Larva. Greatly enlarged. (Original.)

FIG. 4.—The European rat flea: Cocoon. Greatly enlarged. Note the particles of sawdust and dirt adhering to the surface. (Original.)

Close trade communication between the nations of the world gives increased channels for the dissemination of various pests and diseases as well as opportunities for the furtherance of knowledge and the exchange of trade commodities. The colonization of new lands in the Tropics, the opening of a great artery of trade intimately connecting many of our ports with the commerce of the world, the immigration brought about by the present European strife—these, when considered together with the fact that plague is now present in many quarters of the globe, should impress all with the importance of exercising great care to exclude the disease from our shores. Knowing that this pestilence spreads among people only as a result

of the dissemination of the disease among rodents by fleas, the importance of rodent destruction and of flea control, which go hand in hand, needs no further emphasis. It is not sufficient for the farmer, merchant, and others concerned to depend upon the quarantine authorities to keep plague from being introduced. They must aid the quarantine officers by waging war on the rats and ground squirrels and by preventing flea breeding.

Turning from the rat as a sanitary menace, ample argument is found for its destruction on account of its importance as a destroyer of various agricultural and food products. It has been conservatively estimated that there are in the United States at least as many rats as people. It has also been computed that the annual upkeep of each animal amounts to between $1 and $2. From these figures it is seen that the annual loss due to these rodents must be upward of $100,000,000.

The control of rats is difficult but not impossible, the principal methods being trapping, poisoning, destruction by natural enemies, and, probably most important of all, rat proofing. The question of the relation of rats to man has been treated in publications of the Public Health Service and of the Bureau of Biological Survey.[1]

This work of rodent destruction, clearing up of breeding places, and rat proofing of buildings has an important beneficial influence on flea conditions. Some of the hosts of the fleas are removed and the breeding places of the insect destroyed to some extent. However, these practices can not be depended upon to control all of the species of fleas important as pests.

KALA-AZAR.

One form of another important group of diseases of the Tropics, known as kala-azar, an infectious fever, is considered by some authorities to be carried by the dog flea and human flea. The particular form of the malady in question occurs in the Mediterranean region. On these shores dogs and children are attacked by a similar disease. Investigators have produced strong evidence that the disease is identical in the two hosts and that fleas are responsible for its transference from the one to the other.[2]

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[1] Lantz, D. E. How to destroy rats. U. S. Dept. Agr., Farmers' Bul. 369, 20 p., 5 fig., 1909.

[2] Fleas and dogs.—In Europe with regard to infantile kala-azar, the dog has been found to harbor Leishmania, and a fairly presumptive case has been made out as to the part this animal plays as an intermediary host, the dog flea being the actual transmitter. Donovan believes, however, that the evidence adduced so far is not in all respects convincing. The occurrence of a natural flagellate of the flea has evidently not been taken into sufficient account. (Donovan, Lieut. Col. C. Kala-azar, its distribution and probable modes of infection. *In* Jour. Trop. Med. London, v. 16, no. 16, p. 253–255, 1913.)

LEPROSY AND OTHER DISEASES.

Leprosy is another serious malady with which, according to some investigators, fleas may be connected. This relationship has not been established, but it is well for us to consider all such possibilities. The part fleas play in the life economy of certain tapeworms has been mentioned, as has also their connection with certain rat-infesting organisms. Various other low forms of animal life, many of which are no doubt parasites of the flea itself, have been found in the organs of that insect in different stages of its life.

FLEAS AS PARASITES OF MAN AND ANIMALS.

As has been shown, a considerable number of the common fleas of this country may be concerned in the transmission of certain diseases if these are once introduced. Several species are, however, of much importance to man aside from their possible connection with disease. It is with the fleas which annoy man or attack poultry or dogs that the people in general are most concerned.

The effect of the bites of fleas varies much with the individual attacked and also with the identity of the flea concerned. The direct effect of these bites, aside from disease transmission, has received little attention. Usually in man pronounced red, itching papules, in some cases with whitish centers, occur at the site of the puncture. Some more susceptible individuals show marked irritation, swelling, and even ulceration following attack. The papules may persist for several days, but usually disappear within a few hours. The irritation is probably induced largely by the injection of the salivary secretion into the wound. This injection causes a rush of blood to the spot, which facilitates the feeding of the insect and in turn causes irritation in the host. The question of acquiring immunity to annoyance by fleas is an interesting one. Many cases have been reported wherein individuals have enjoyed marked immunity to the effect of fleabites and comparative freedom from annoyance after being exposed to the fleas of California. The species concerned in these instances was without doubt the human flea. Others report a similar diminution in the annoyance caused by the dog flea. A brief discussion follows of the more important species from the standpoint of annoyance to man and domestic animals.

THE HUMAN FLEA.

The species of flea known scientifically as *Pulex irritans* L. has long been considered the human flea. It is to be found in practically every portion of the earth frequented by man. It is quite distinct from other fleas in structure (figs. 5 and 6), and is largely dependent

upon man as a host, although in Europe it seems to thrive on the badger, while in the United States it is commonly taken on the skunk. It has also been taken on hogs, rats, and various other animals, but these are usually but temporary hosts and insufficient to maintain the species.

On the Pacific coast the species is responsible for practically all annoyance to man due to this group of parasites. It has been found to be the one concerned in nearly all cases of house infestation in that section. In the Southern and Eastern States, as will be pointed

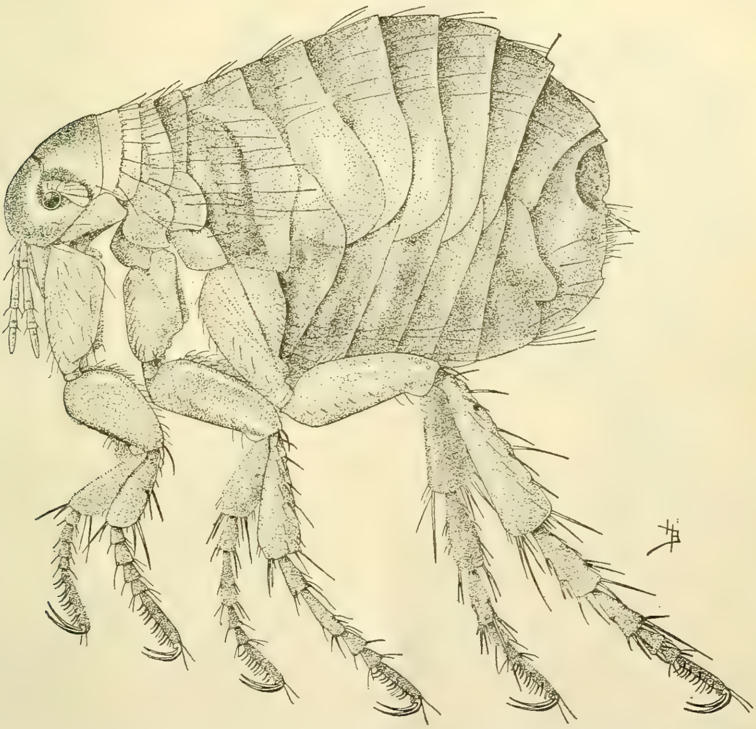

FIG. 5.—The human flea (*Pulex irritans*): Adult female. Greatly enlarged. (Original.)

out later, the dog flea is more important as a pest to man than the human flea. Our main interest in the human flea is on account of its annoyance to man, as it is not as yet known to play any part in disease dissemination in this country. Nevertheless, the possibility of its being an occasional carrier of plague and also that it may transmit the infectious fever kala-azar of the Mediterranean region should not be lost to sight.

Curiously enough, the human flea appears to have adapted itself to the varied conditions under which man lives. It breeds freely in all situations occupied by man, and in the immature stages is one of the most hardy species known to science. The biology of this species,

as compared with others, has been briefly outlined in the preceding pages, and control measures, applicable to this and most other species, are discussed in the following pages.

THE DOG FLEA.

The dog is undoubtedly the normal host for the flea which is known scientifically as *Ctenocephalus canis* Curtis (fig. 1); nevertheless the insect is not averse to partaking of a meal of blood from man or a cat, especially when its normal host is not at hand. Like the

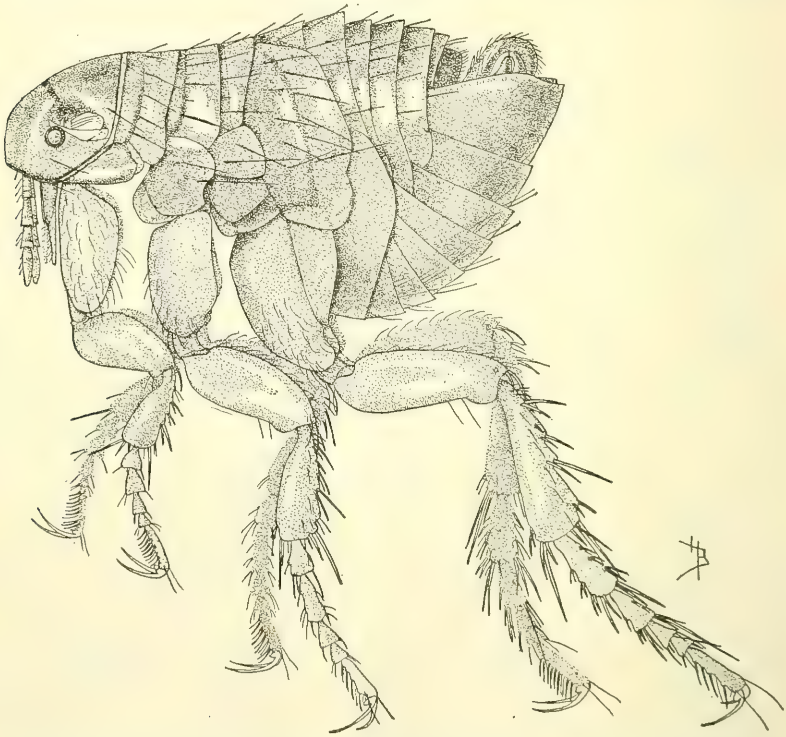

FIG. 6.—The human flea: Adult male. Greatly enlarged. Note the difference in the shape of the abdomen of the male as compared with the female (fig. 5). (Original.)

human flea, this species has a wide distribution throughout the world; in fact, it is generally considered the most widely distributed species of flea.

As an annoyer of man the dog flea ranks next to the human flea. In the eastern United States, as has been pointed out by Dr. Howard, instead of the human flea this is the species usually reported as infesting houses. In some instances reported to the Bureau of Entomology houses have been rendered almost uninhabitable by this aggressive insect. The most severe infestations, as reported by Dr. Howard, have occurred in cases where dwellings have been closed up during summer, and when opened upon returning the occupants were greeted

by hundreds of fleas. Rainy summers are most favorable for such development, supplying enough dampness to the dust, which is left undisturbed in the cracks, successfully to mature the eggs and fleas which are present. The original stock of fleas must, of course, be derived from pet dogs or cats which occupied the house before it was vacated, or, as often happens, dogs may take up their abode under or around the house in the absence of the occupants Thus great numbers of eggs are dropped, and breeding proceeds undisturbed. It should be noted that the stray dogs and cats which are likely to find homes in unoccupied buildings are often heavily infested with fleas, usually much more so than animals with a home and having more or less attention paid to them.

In this country the dog flea is not known to be responsible for the transmission of any disease, but it holds a position of distinct importance as a household pest. Its importance as an enemy of the dog and cat is not small. Breeders of fine cats and dogs often have considerable trouble in ridding their stock of fleas, and hunting and other dogs, particularly in the South, are kept in poor condition as a result of gross infestation. The fact that one stage of a tapeworm which commonly infests dogs and occasionally children in this country lives within the dog flea still further increases the importance of this parasite.

THE STICKTIGHT FLEA.[1]

One need but visit a few poultry farms or inquire of almost any farmer with his little flock of chickens for home use in the southern and southwestern portions of the United States to get some idea of the importance of the so-called "sticktight flea" (*Echidnophaga gallinacea* Westw.). Other colloquial names which are applied to the insect are "third-party flea," "chicken flea," or "black flea." The name chicken flea is applied because of the frequency with which chickens are infested. Black flea is a name applied less frequently and is given on account of the very dark color of the adult fleas. The name "sticktight" is used most generally in the South, and it is aptly applied. The species differs markedly in feeding habits from most of our common species. It seldom hops about, biting here and there, as in the case of the dog and human fleas, but when a suitable host is found it settles down, deeply inserting the mouth parts, and remains

[1] In a publication just issued (Herrick, Glenn W. Some external parasites of poultry with special reference to Mallophaga, with directions for their control. Cornell Univ. Agr. Expt. Sta. Bul. 359, p. 230–268, fig. 95–116, Apr., 1915.), the point is brought out that the European hen flea, *Ceratophyllus gallinae,* was received from Abington, Mass., and Barker, N. Y. In each of these cases the flea was collected in hen houses, and the collectors state that the insect was very annoying, especially to human beings. Prof. Herrick calls attention to the fact that Mr. C. F. Baker reports the collection of a single specimen of this flea at Ames, Iowa, and refers to a note by Dr. M. Francis to the effect that the species occurred at Bryan, Tex. It is possible that in time this insect may become a pest of some importance to poultry in the United States.

for days or weeks. Its hold on the host is difficult to loosen. Another marked tendency is for the adults to attach to hosts in dense masses. A chicken is frequently seen with a large portion of her head closely set with these fleas, making it appear almost black. These dense masses are often seen on the ears of dogs or cats, particularly at the very edge of the ear. The characteristic appearance of an infested chicken's head is shown in figure 7.

The hosts of this flea are, unfortunately, rather numerous. As has been stated, chickens are commonly attacked, and it is on this host that the species assumes its greatest importance as a pest. In the investigations by the author it has been found in abundance on dogs, cats, tame rabbits, ducks, and turkeys. It is not infrequently found on people who go about infested poultry yards, and children, crawling beneath houses where infested animals go, are often bitten. The species does not attack man very freely. It is seldom found in houses except on rare occasions, when a few specimens may be brought in on the clothing. In one instance in western Texas a burrowing owl was killed and found to be heavily infested about the head with this flea. In another instance in the same region a wood rat, or pear rat, as it is commonly known there, was found to harbor a number of sticktight fleas. Several years ago Prof. J. C. Hartsell, of Orangeburg, S. C., reported to the Bureau of Entomology instances where horses were heavily infested with these fleas on the lower portions of the legs. Others have recorded it from cattle, and a number of specimens have been taken on rats and other hosts in different parts of the world.

FIG. 7.—Head of rooster infested with the sticktight flea (*Echidnophaga gallinacea*). Somewhat reduced. (Original.)

The species was originally described from India, but it now appears to be widely distributed throughout the Tropics and the warm temperate regions. In the United States it is seldom seen north of the Southern and Southwestern States. Reports indicate that the species is spreading; at any rate, it would seem that the South is becoming more generally and completely infested.

No disease has been found to be carried by the sticktight flea, but its importance as a parasite places it among the principal insect enemies of poultry in the South. The principal direct loss is due to the attack of the fleas on young poultry, as high as 85 per cent of young

chickens hatched having been reported lost on account of the fleas. In many cases young chickens, turkeys, and ducks have a combined infestation of sticktight fleas and biting lice, and each contributes to the worriment and weakening of the fowls. A few cases of death observed among grown chickens apparently have been due to fleas. In these instances not only the heads and necks of the chickens were largely covered but numerous patches thickly set with fleas existed under the wings and on the breast. The fowls heavily attacked become droopy, lose appetite, and fall off in weight. Mild infestations on grown fowls cause no marked injury, but no doubt egg laying is influenced to some extent, and certainly infested fowls are unsightly.

The fleas are present on hosts throughout the year, but they are usually more numerous in the summer and fall. The species appears to thrive best in ill-kept chicken houses, where chickens roost under buildings, and where dogs and cats have their beds closely associated with the poultry. This point will be discussed further under the general topic of control. The eggs are dropped by the females while attached to the host. These fall beneath the roost, hatch, and the young larvæ feed on the excrement of the parent fleas and on other animal and vegetable refuse.

FIG. 8.—The sticktight flea: Adult female. Much enlarged. (Original.)

The species is one of the smallest fleas in this country and very dark brown in color. The body is comparatively short and deep, and the legs are slender, but the mouth parts are large and strong. The male is usually slightly smaller than the female (fig. 8), almost black, and is more frequently seen moving about on the host than the female.

THE CHIGOE FLEA.

The flea commonly known as the chigoe or "jigger" (*Dermatophilus penetrans* L.)[1] is related to the sticktight flea, but has different

[1] This should not be confused with the "chigger" or harvest mite, which is the larval form of Trombidium.

habits. Instead of remaining attached to the surface of the host, the female, after being fertilized, burrows into the flesh until it may become completely embedded. When it first reaches a host it feeds much as does the sticktight flea, the burrowing tendency becoming evident only when the eggs are developing. A number of hosts are attacked, particularly the hog. Cats, dogs, cattle, sheep, horses, and even birds are attacked, but attention has been directed to the species largely through its infestation of man. Its attack is usually confined to the feet of the host, and in man particularly to the toes. The females may enter between the toes or under the toenails, and severe inflammation often follows, with the formation of ulcers, frequently resulting in permanent crippling. While in the host the eggs develop within the female and the abdomen becomes greatly distended, often attaining the size of a small pea. The legs of this species are not large, and when this distention takes place they, as well as the head, become very inconspicuous.

The eggs are deposited while the flea is attached and may drop from the wound or pass out with the detached flea. So far as known the rest of the life history is similar to that of other species.

The chigoe is not known to be established in the United States, although it has been reported on a few occasions from Florida. It is a troublesome pest in the West Indies, in parts of Mexico, and in much of South America. It is native to the American Tropics, but about 1872 it was introduced into western Africa. The African conditions were favorable for the pest, and it soon became established in east Africa and Madagascar and spread to the interior of the continent. It was introduced more recently into India, but it appears to have spread very slowly there.

Conditions in Florida and southern Texas would seem to be favorable for this insect, and if care is not exercised it may be introduced and become established in this country.

NATURAL CONTROL.

As has been stated, hot, dry weather is detrimental to flea development. Likewise excessive moisture in a breeding place destroys the immature stages. The direct rays of the sun in summer are important in reducing the length of life of the adult flea and destroying the immature stages. It is possible to take advantage of these natural factors to a considerable extent in fighting the pest, as is brought out later.

Little is known of the natural enemies of fleas. Certain short-winged beetles termed staphylinids are known to prey upon the adult fleas, and certain species of mites have commonly been found upon them. In Texas ants have been observed to prey upon the eggs and

larvæ. No doubt a number of insect enemies of the immature stages exist, but they are probably less important in control than climatic factors. Chickens seem to be capable under some conditions of interfering with the development of the immature stages of fleas by scratching their breeding place about, and no doubt they eat some of the fleas in their various stages.

ARTIFICIAL CONTROL.

In order to prevent an outbreak of fleas, and more especially to control an infestation which has become established in or about a house, it is usually necessary and always advisable to combine two or more of the measures discussed below in order promptly to control the situation.

DESTRUCTION OF FLEAS ON HOSTS.

In nearly all cases of flea infestation by either the human flea or the dog flea in houses or by the sticktight flea in poultry yards the destruction of the fleas on the hosts is important. Dogs and cats are the animals of particular importance in this connection, since they act as normal hosts for the flea of the dog and cat, which often annoys man; they sometimes harbor the human flea and are frequently heavily infested with the sticktight flea. In cases of house infestation, while it is imperative that the breeding places be treated, attention should be given to dogs and cats. In fact, the destruction of the breeding places and the clearing of the fleas from the hosts should be undertaken simultaneously, as each is essential to the best success of the other. A number of different methods of destroying the insects on animals have been tried, and each has its advocates. The writer has used certain creosote derivations, among them creolin, with excellent results. There are several preparations similar to creolin which would probably be equally effective. It is best to make up a 3 per cent solution of creolin, or one of the similar preparations, in warm water in a tub and place the animal into it; then with a stiff brush to work the solution into the hair. The animal should be kept in the solution 5 or 10 minutes, particular care being taken thoroughly to wet the fleas which crowd to the head of the animal. After the host has been thus treated the creolin water may be drained off and the animal washed with warm water and soap. This washing is not always necessary or advisable in treating dogs, but it is desirable with cats. By this method the burning of the most delicate-skinned animal is avoided. Where a graduated glass measure is not at hand, a 3 per cent solution of the wash may be made by putting in 4 tablespoonfuls of creolin to each gallon of water.

Another treatment, which is reported by Mr. A. A. Girault, of the Bureau of Entomology, to be effective in ridding cats of fleas, is naphthalene. Moth balls were finely pulverized and the powder worked into the fur. The fleas soon began coming out of the hair and on account of their stupefied condition were easily caught and killed. The treatment slightly sickened the cats for two days, but had no serious effect. Insect powder, sometimes called pyrethrum, buhach, or Dalmatian insect powder, may be applied to the fur of animals in the same way. It is not harmful to the host and causes the fleas to come out of the fur in a stupefied condition, when they may be collected on a newspaper and destroyed by burning. It is important that fresh unadulterated pyrethrum be used to secure satisfactory results. The destruction of the chicken flea or sticktight on poultry seems to be rather difficult. Where heavy infestations are present the careful application of kerosene and lard—1 part kerosene to 3 parts of lard—to the masses of fleas gives fairly good results. Care must be taken not to apply too much of the mixture and not to get it on the parts of the fowl where it is not necessary, as it will prove injurious if used too freely.

CONTROL OF HOSTS.

One of the common practices to avoid flea infestation of houses is to keep all dogs and cats out of doors. This is often not desirable, and it also gives an opportunity for the infested animals to start breeding places under the house or in the yard or barn, hence this practice without treating the animals for fleas is objectionable. Not keeping dogs or cats will, of course, largely solve the dog-flea problem, but this is not always feasible. Moreover, the stray animals must also be considered as possibilities in house infestation. From the standpoint of flea control, as well as for the prevention of important diseases, the strict enforcement of dog-control measures and the destruction of all stray cats and dogs is imperative. Dwellings and other buildings should be arranged to prevent cats, dogs, hogs, chickens, and other animals from going beneath them, as the conditions under buildings are often favorable for flea breeding and these locations are exceedingly difficult to keep clean or treat after infestation is started. Numerous instances have come under observation where such conditions were responsible for infested dwellings and heavily infested animals.

Along this same line is the question of separation of hosts. It is bad policy to keep all kinds of animals in close proximity in localities where fleas are numerous. Dogs and cats sleeping around poultry pens are often responsible for keeping chickens constantly stocked with sticktight fleas. Horses kept in buildings where chickens roost

or in barns adjoining chicken coops have been known to become infested with sticktight fleas, and dogs and cats readily infest one another with these and with other fleas. Chickens have been known to become infested with chicken fleas and thus establish an infestation in uninfested yards when allowed to run at large and come in contact with infested premises.

The question of rat control logically should be discussed under this topic, but it has been briefly taken up under "Bubonic plague." Ground-squirrel destruction, aside from its direct economic importance, should also be considered in connection with the relationship between the squirrel fleas, their hosts, and the transmission of plague. The ground squirrels of California are discussed by Dr. C. Hart Merriam in Circular No. 76 of the Bureau of Biological Survey. Much useful information on the control of the California ground squirrel is given, and this is for the most part applicable to ground squirrels in other parts of the country.

DESTRUCTION IN BREEDING PLACES.

Attention has been called (pp. 8–9) to the usual breeding places of different species of fleas. It is evident that destruction of the adult fleas on hosts is almost a hopeless method of controlling the pest if no attention is paid to the breeding places of the immature stages. As has been stated, flea eggs may produce adult fleas from two weeks to many months later. Thus the hosts will continue to become reinfested as fast as the insects upon them are destroyed.

The first step in making war on the breeding places is to determine where the fleas are coming from. Enough has been said in the discussion of life history and breeding habits of fleas to point out the places to be considered. In other than house infestations all unnecessary rubbish and dry animal or vegetable matter should be piled up and burned. In the case of infested chicken houses or sheds the manure should be hauled into an open field and scattered thinly over the ground. When thus exposed all stages are soon destroyed.

Following this preliminary work, which is essential to the success of the subsequent treatment, the ground, outhouse floors, and other places where the breeding is supposed to occur should be sprayed with kerosene, or, better still, crude petroleum should be sprinkled freely about. To prevent reinfestation or breeding it is essential that all waste, both vegetable and animal matter, be kept scrupulously cleaned up. The most inexpensive and satisfactory preventive measure following the destruction of the main infestation is a liberal use of salt scattered about the breeding places and then thoroughly wet down. In many instances observed in Texas the sticktight flea has been kept out of poultry runs by cleanliness

and semiweekly wettings with water. Along the coast salt water from the Gulf is used extensively for this purpose. The soil must be thoroughly wet, as light sprinklings of the surface will not suffice. The watering is most effective when done in the evening, as drying does not proceed so rapidly then as during the day. Mr. D. L. Van Dine, in treating premises infested with the dog flea in Hawaii, used a dressing for the ground under the houses consisting of 20 pounds of air-slaked lime, 3 pounds of sulphur, and 1 pound of buhach. This mixture was applied after the ground had been thoroughly cleared of all refuse. The outbreak was completely controlled in these cases, but it is difficult to say just what part the above dressing played, as the destruction of the adult fleas was undertaken, as well as other measures.

The breeding of the sticktight flea may be prevented to some extent by the use of metal chicken houses, as is advocated for the fowl tick.[1] These galvanized-iron houses provide less protection for fleas than do frame structures, and the intense heat within them during the daytime practically prohibits flea breeding. The dog house should be cleaned out thoroughly at weekly intervals, and if any flea breeding starts the method of destroying the insects, as outlined in the preceding paragraphs, should be followed. By providing a few gunny sacks or a mat for infested animals to sleep upon, it is possible to concentrate the eggs on these. The eggs may be destroyed then by shaking the cloths over a fire or even out on the bare ground in a place exposed to the sun. This should be done about every second day in order to prevent hatching.

Attention is directed to house infestations, which, by the way, are often supplemented by infestations under the houses or in other out-of-door situations. The occurrence of fleas in dwellings is often connected with the keeping of a cat or dog indoors. If this is the apparent source of infestation, the animal should be treated as previously described and kept out until the indoor work is completed.

If the hosts have been confined largely to one room, this is the one to receive most careful attention. The floor covering should be removed, aired, and beaten, the floor thoroughly swept, and all of the dust obtained should be burned, as it contains many immature fleas. It is best, then, to scrub the floor with strong soapsuds or sprinkle it with gasoline, being careful to avoid having fires about. After sprinkling naphthalene crystals or insect powder over the floor, return the floor covering.

Dr. Henry Skinner, of Philadelphia, found that he could control fleas completely in a house by taking one room at a time, scattering

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[1] Bishopp, F. C. The fowl tick. U. S. Dept. Agr., Bur. Ent., Cir. 170, 14 p., 5 figs., 1913.

5 pounds of flake naphthalene over the floor, and closing the room tightly for 24 hours. This remedy was found inexpensive, as the naphthalene could be swept up and transferred to another room.

Dr. Howard has called attention to the method of control used by Miss Adele M. Fielde, who has had extended experience with fleas in China. She states that it is possible to control the fleas there by the use of alum. This substance is added to the whitewash or calcimine used on the walls, paper is dipped in a solution of alum and put under rugs and matting, and powdered alum is sprinkled on carpets or other floor covering and swept in. It does not injure the rugs or matting, but banishes the insects, according to Miss Fielde's statements.

In houses where vacuum cleaners are used at frequent intervals the number of fleas coming from the floors may be reduced. In cases of infested houses a thorough cleaning of the carpets and floors with a vacuum cleaner, provided it is efficient, would largely mitigate the pests.

Fleas in different stages in dwellings or other buildings may be destroyed by fumigation with sulphur fumes or hydrocyanic-acid gas. Either of these fumigants, when properly handled, will destroy the fleas, and has the advantage of killing the rats and mice as well. The use of sulphur [1] is efficient and simple, but has the objection of corroding metal and injuring plants. In fumigating, the infested building should be closed up tightly and the sulphur weighed out at the rate of 4 pounds to each 1,000 cubic feet of space. The sulphur is piled up cone shaped in a pan or kettle, which is placed in a larger pan or tub of water to avoid fire from the heat generated. A depression should be made in the top of the cone of sulphur, a little alcohol poured into it, and a match applied. Each room to be fumigated should have a vessel, and large rooms should have two, one located near each end. It is preferable to do all of the fumigation simultaneously. The rooms or building should be kept closed for from 10 to 12 hours. Although this gas is not nearly so dangerous to man as is hydrocyanic-acid gas, the rooms should be thoroughly aired before entering them. The corrosive action of the gas on metals and its effect on plants should not be overlooked. This may be minimized by fumigating when the atmosphere is dry.

Owing to the poisonous character of the ingredients used and the deadliness of the gas generated, fumigation with hydrocyanic-acid gas should not be undertaken without carefully reading the directions [2] for the operation, and then only by an experienced person.

[1] Marlatt, C. L. Sulphur dioxide as an insecticide. *In* U. S. Dept. Agr., Bur. Ent., Bul. 60, p. 139–146, 1906.

[2] Howard, L. O., and Popenoe, C. H. Hydrocyanic-acid gas against household insects. U. S. Dept. Agr., Bur. Ent., Cir. 163, 8 p., 1912.

Sodium fluorid is a comparatively new insecticide which will probably be useful against fleas. This substance is not expensive and not dangerous to handle. The crystalline powder is applied by dusting it over the carpets or floors and working it into the cracks. For the adult fleas it may be blown about the floor and corners with a dust gun or insufflator. Although this substance has not been tried in this way, it is possible that it can be advantageously utilized in chicken houses, dog kennels, etc., by blowing it about the floors with a powder gun. The fact that sodium fluorid is an excellent remedy against cockroaches further commends its use about houses infested with fleas.

A number of things should be mentioned which may be utilized to some extent in flea-infested regions to prevent the breeding of fleas in dwellings. As far as possible, rugs, or art squares, or other coverings which can be taken up and permit keeping the floors more cleanly, and in case of infestation make treatment easier, should be used. Closely matched floors are beneficial, as there are fewer cracks in which the young fleas may develop. Where cracks are present they may be filled with plaster of Paris or putty. The use of floor oil or of efficient sweeping compounds on floors seems to aid in preventing flea breeding.

TRAPPING FLEAS.

Little dependence for control of fleas can be placed on methods designed actually to capture, repel, or exclude from the host the adult fleas if not supplemented by the other repressive measures just discussed. Nevertheless, under certain conditions, such as in instances where a few adults are produced in a great number of situations, thus making complete stopping of breeding very difficult, or while the other methods of control are being put into effect, trapping, repelling, and isolating are of some value. In localities where plague is prevalent, or even suspected, the importance of keeping even a single flea from biting man is apparent.

Where only a few fleas are present in a dwelling and breeding in the floors is not suspected, the adults may be caught by placing a number of sheets of sticky paper on the floor. In extreme cases, where the persons attempting to rid premises of fleas are liable to injury or serious disease, the practice of wrapping fly paper, sticky side out, around one's legs and walking about is sometimes resorted to. The movement causes the fleas to jump, and if they strike the paper they are held fast. The use of sticky fly paper in this way was probably first tried by Prof. S. H. Gage at Cornell University. One of the university buildings was cleared of fleas by having the janitor, with legs wrapped in fly paper, walk back and forth in the infested rooms. Mr. D. L. Van Dine also made use of this scheme in Hawaii.

In this instance, however, it was used mainly to protect the workmen who were clearing up flea-infested premises.

Lights have been used as traps for the adults in some instances. The results will no doubt vary with the species of flea concerned. A light trap which was used by Mr. E. M. Ehrhorn, formerly of San Francisco, is described by Dr. Howard, as follows:

> Fill a glass three-fourths with water, on top of which pour about an inch of olive oil, then place a night float (a little wick inserted in a cardboard disk or in a cork disk) in the center of the oil. Place the tumbler in the center of a soup plate filled with strong soapsuds. The wick should be lighted at night on retiring, or may be used in any dark room. As the soup-plate soapsuds trap is placed on the floor of the room, it does not interfere with the sleeper, and the fleas which are on the floor are attracted to the light.

A small flea trap which is extensively used in parts of China, and is said to be very beneficial, has recently been described by Dr. E. Hindle. In China two pieces of bamboo are used in constructing the trap. A modified form of this trap, which can easily be constructed by anyone, is illustrated in figure 9.

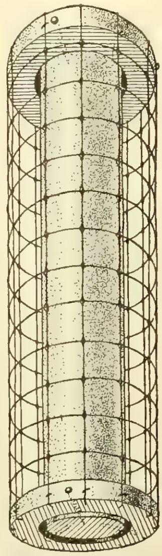

Fig. 9.—Flea trap. The central cylinder is removable and is covered with sticky fly paper. (Original.)

To construct the trap, bore two holes, about an inch and a quarter in diameter, in a board anywhere from one-fourth to 1 inch in thickness. With a keyhole saw or a pocket knife cut out a disk of the board around each of the holes about $2\frac{1}{2}$ inches in diameter. Take a piece of wire netting, with one-fourth or one-half inch square soldered mesh, about 2 feet wide, and tack it around the disks, having one at either end. Cut off the wire, leaving the ends long enough to overlap along the side of the cylinder, and bend the ends in to complete the cylinder. Around a broom handle or other stick about an inch in diameter and equal to the length of the cylinder wrap a piece of sticky fly paper, sticky side out; tack it at each end to the stick and insert the stick into the cylinder. The stick should be fastened in with a nail inserted into it through a hole in the edge of one of the wooden ends. The outer wire cylinder forms a protection for the sticky surface and enables one to move the flea stick around between the bed sheets or to roll it over the flea-infested floor, thus disturbing the fleas, which are caught on the sticky paper. The stick may be easily removed and a new piece of fly paper put on when necessary.

Animals have been used as traps for fleas in experiments conducted by the Indian Plague Commission and others. The Commission

found that guinea pigs left free in rooms picked up considerable numbers of fleas of different species. Men also acted as traps by going about in an infested room, and the fleas thus picked up were caught. No doubt rabbits, cats, or dogs could be utilized in the same way and the fleas destroyed by the methods mentioned under "Destruction of fleas on hosts." This method of picking up fleas is sometimes applicable to certain places in districts where plague exists and it is desirable to capture and destroy the few fleas which might otherwise get upon man.

The use of fresh meat to attract fleas onto fly paper and into traps has been considered to have some merit, but tests made by Drs. Howard and Mitzmain and by others show that it is without value.

REPELLING FLEAS.

The usefulness of repellents is even more limited than that of traps. Many things have been advocated from time to time, or in different sections of the country, for the driving away of fleas. Oil of pennyroyal is probably most widely used for this purpose, and it seems to have considerable virtue as a repellent. This substance may be applied to the shoe tops, hose, and trousers, or placed elsewhere on the body or clothing, and its use on bedding and floors has been advocated by those in flea-infested regions. The pennyroyal plant is used for the same purpose where it grows. Buhach, oil of cedar, eucalyptus oil, or camphor sprinkled between the sheets give a degree of protection to those compelled to sleep in flea-infested places.

ISOLATION FROM FLEAS.

Frequently in many parts of the country outbreaks of fleas are experienced. In such cases extreme measures are necessary for any degree of comfort. Knowing that fleas have very limited powers of jumping in a vertical direction and of crawling on smooth surfaces, it is practicable to exclude them from beds. The higher the bed is from the floor the better, but one may isolate the bed from fleas in most standard-height beds if care be taken to keep the clothing from hanging down. Of course it is essential that no fleas be taken into the bed on the body or the night clothing and that the bedding does not touch the walls or baseboard. It is possible also to isolate a bed or cot or a person sleeping on the floor, if the floor itself is not infested, by placing a band of sticky fly paper or paper covered with a sticky substance 14 inches wide around the bed. In case the legs of a bed are rough, which permit fleas to crawl up them, a band of sticky substance may be painted around the bottoms from 4 to 5 inches above the floor, or, if more convenient, the legs of the bed may be placed in large pans of water.

When the fleas are carriers of disease they are, of course, much more dreaded than when their greatest injury is their bite. Where extreme measures are needed the possibility of a man's protecting himself from fleas while working in infested locations or even while sitting in an infested room by wrapping his legs with fly paper should be borne in mind. A man may get considerable protection from the sticktight flea by wearing khaki or denim trousers and having them tucked into hightop shoes. Leather boots with the tops on the outside of the trousers also keep many fleas from gaining access to the body.

REMEDIES FOR BITES.

As has been stated, fleas in the act of biting inject saliva into the wound, thus producing more or less irritation and itching. Ordinarily no treatment of the bites is necessary; but where they are numerous, especially in the case of susceptible persons, cooling lotions will give relief. Menthol and camphor are beneficial, and carbolated vaseline, carbolic acid in water (a 3 per cent solution), and hydrogen peroxid are each said to relieve the itching and inflammation.

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LOGAN WALLER PAGE, Director

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PORTLAND CEMENT CONCRETE PAVEMENTS FOR COUNTRY ROADS.

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CONTENTS.

INTRODUCTION.

The purpose of this paper is to supply reliable information on the subject of Portland cement concrete pavements for the use of highway engineers and others interested in the improvement of public roads. It is realized, however, that the present state of knowledge concerning the best methods of constructing such pavements is by no means complete, and those who have charge of concrete-road construction should be careful to keep themselves informed regarding results obtained by others engaged in similar work and by laboratory experiments.

The earliest concrete pavement in the United States of which there is reliable record was constructed at Bellefontaine, Ohio, during 1893 and 1894. This pavement contains 4,400 square yards and was constructed in squares similar to those employed in concrete sidewalk construction. The concrete was laid in two courses. This early experiment indicated many possibilities and no doubt has been responsible for some of the construction methods in use at present. Prior

NOTE.—This bulletin contains reliable information on the construction of Portland cement concrete pavements for country roads. Practical instructions for highway engineers and all others interested in road making are given.

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to 1909 the total area of concrete pavements which had been constructed in this country was comparatively small, and in the majority of cases these pavements were frankly regarded as experiments. During 1909 the road officials of several communities concluded that the results already obtained were sufficiently encouraging to warrant them in undertaking the construction of concrete roads on a larger scale, and since that time many such roads have been completed. Wayne County, Mich., was one of the first communities to adopt this form of construction and at present probably has a greater mileage of roads paved with concrete than any other county in the United States.

The fact that the majority of the concrete pavements which have been constructed have proved entirely satisfactory where traffic conditions were not unduly severe is serving to increase their popularity very rapidly. This is evidenced by the following tabulation, showing the approximate number of square yards of such pavements that have been constructed in the United States each year beginning with 1909:

	Square yards.
1909	364,000
1910	850,000
1911	1,800,000
1912	6,470,000
1913	10,100,000
1914 (estimated)	19,200,000

Enthusiastic advocates of concrete roads should bear in mind that such roads can never be economically adapted to all traffic conditions, and those who are in responsible charge of road-improvement work should realize the importance of making a careful economic comparison of the various kinds of road surfaces under the conditions to be met before deciding upon the type of improvement to adopt.

The principal advantages which concrete pavements possess may be briefly stated and commented upon as follows:

1. As far as can be judged, they are durable under ordinary suburban and rural traffic conditions. While it is true that there are no very old concrete pavements in existence, the present condition of many of those which have undergone several years' service would seem to warrant the above statement.

2. They present a smooth, even surface, which offers very little resistance to traffic. In the past the surfaces of concrete pavements have sometimes been roughened in order to insure a good foothold for horses. This practice has now been abandoned, except on very steep grades, because it tends greatly to accelerate deterioration of the pavement, and because the smooth surface has been found to afford a fairly satisfactory foothold under all ordinary conditions.

3. They produce practically no dust and may be easily cleaned.

4. They can be maintained at comparatively small cost until renewals become necessary.

5. They may be made to serve as an excellent base for some other type of surface when resurfacing becomes desirable.

6. They present a pleasing appearance.

The principal disadvantages are:

1. They are somewhat noisy under horse traffic.

2. There is no method of constructing necessary joints in the pavements which will entirely prevent excessive wear in their vicinity. Furthermore, joints do not altogether eliminate cracking, and wherever a crack develops it must be given frequent attention in order to prevent rapid deterioration of the pavement.

3. They can not be as readily and effectively repaired as many other types of pavements.

MATERIALS AND CONSTRUCTION.

It is especially desirable that concrete for road pavements should possess, in as great degree as practicable, (1) hardness, in order to resist the abrasive action of traffic; (2) toughness, in order to resist the disintegrating action of horses' hoofs and other shocks; and (3) homogeneity, in order that the surface may wear uniformly.

The character of the constituent materials and the proportions in which they are mixed both have a marked influence on the degree in which these qualities are possessed by the concrete. In selecting the materials and determining the proportion in which they are to be mixed, the prospect of securing the desired qualities in the resulting concrete should be given primary consideration. The methods of mixing, depositing, and curing the concrete are also important factors in securing satisfactory results and will be discussed in their proper places.

MATERIALS.

No hard and fast rules can be laid down which would fit all cases in the selection of concrete materials, as availability is necessarily a very important factor. Satisfactory cement can usually be obtained, and none should be used in constructing pavements which does not meet all the requirements for a high-grade Portland cement. The cost of importing the sand and coarse aggregate from any considerable distance is usually prohibitive, and if there are any local materials which are or can be made suitable for aggregates they should be given first consideration. But if the local materials are not such as to meet substantially the requirements outlined in the following paragraphs, it would be very doubtful economy to use them.

CEMENT.

Portland cement of a character satisfactory for use in pavement construction is at present manufactured in nearly every section of the country. The product of all cement plants is not always entirely uniform and of equal excellence, and even if it were uniform immediately after manufacture this condition might easily be changed by age or exposure. These facts make it imperative that cement for use in concrete pavements be subjected to very rigid inspection. It should be known to conform to the requirements of some standard specification for Portland cement, such as that contained in Circular 33 of the United States Bureau of Standards or that issued by the American Society for Testing Materials.

SAND.

Sand for use in concrete pavements should be selected with especial care. The strength of mortar depends almost, if not quite, as much on the quality of the sand used as on the quality of the cement, and a strong mortar is imperative if the best results are to be obtained. Preference should be given to sand composed of a mixture of coarse and fine grains, with the coarse grains predominating, though sand consisting entirely of coarse grains is preferable to that in which the fine grains predominate. It is also very important that the sand be as clean as practicable. Sand which contains more than about 3 per cent of foreign materials, such as loam or clay, should be rejected, and no sand should be used the grains of which are coated with clay or other objectionable material.

Sand which contains even a very small percentage of vegetable acids is unsuitable for use in concrete, because such acids seriously affect the strength of cement. It is not always easy to detect the presence of acids in sand, and in order to insure that they are not present in any great extent it is well to specify that cement mortar in which the proposed sand is used will develop a tensile strength equal to that developed by mortar made of the same cement and standard Ottawa sand.

COARSE AGGREGATE.

The coarse aggregate may consist of either crushed stone or gravel. It has been claimed that the angular shape of the particles of crushed stone gives that material an advantage over gravel in the matter of securing a satisfactory bond with the mortar of the concrete, and this claim seems to be at least partially justified by experience. Wherever gravel and crushed stone have been used as coarse aggregates in different sections of the same pavement, and the different

sections have been given identical treatment, a proportionally greater number of cracks have usually formed in the gravel concrete. It has been observed, however, that when some varieties of stone are used as coarse aggregate the resulting concrete shows very little, if any, superiority over gravel concrete as regards the formation of cracks. It therefore seems possible that the quality of stone, rather than the angular shape of the particles, may be responsible for the apparent advantage of crushed stone over gravel.

There are not sufficient data available to warrant making a definite comparison of the advantages possessed by the different varieties of stone when used as coarse aggregate. But so far as cracks are concerned, limestone appears to have made a better record than any other variety of stone which has been used to any considerable extent.

The coarse aggregate, whether of crushed stone or gravel, should possess at least as great resistance to wear as the mortar which fills the voids between the particles of stone. Any sound stone or gravel, moderately hard and tough, will meet this requirement, but in general the harder and tougher the coarse aggregate, the greater the resistance to wear of the concrete. The best available stone should therefore always be used.

The difficulties experienced in securing a satisfactory quality of coarse aggregate are frequently caused by a lack of proper facilities for preparing the natural materials locally available. There are very few gravel pits which furnish a gravel suitable for use in concrete pavement construction without washing, and properly equipped washing plants are both difficult and expensive to construct. On the other hand, a great many stone quarries contain pockets of clay or inferior stone which should not be contained in the aggregate, and it is sometimes very difficult to remove these objectionable materials while the stone is being crushed and screened. It is also frequently difficult to screen out the dust of fracture formed in crushing some varieties of stone.

It is very desirable that the particles composing the coarse aggregate be well graded in size between proper limits in order that the percentage of voids may be as small as practicable. It is convenient to fix the limit of variation by specifying a certain screen upon which coarse aggregate shall all be retained, and another screen which it shall all pass. A $\frac{1}{4}$-inch mesh screen for the lower limit and a screen having $1\frac{1}{2}$-inch circular openings for the upper limit have been most frequently specified for coarse aggregate used in concrete pavements. The upper limit of $1\frac{1}{2}$ inches seems to be entirely satisfactory in nearly all cases, but the lower limit of $\frac{1}{4}$ inch frequently results in a failure to remove as much fine material from the aggregate as is desirable. For example, when the coarse aggregate is se-

cured from gravel containing a considerable percentage of sand, or from crushed limestone, a $\frac{3}{8}$-inch mesh minimum screen is to be preferred.

WATER.

Water used in mixing concrete should be reasonably clear and free from alkalies, acids, vegetable matter, or other injurious materials. The subject of water supply will be later discussed under the heading, "Methods, organization, and equipment."

PROPORTIONING.

Concrete in pavements is subjected to much more severe service conditions than that in walls, foundations, etc. Most of the old rules for proportioning concrete were developed with a view to providing only for simple compressive stresses, such as are met with in the latter class of structures. Hence it is not surprising that the early results obtained for pavements by following the old rules were not generally satisfactory. Concrete pavements must resist not only crushing and impact stresses but the wearing action of traffic as well, and this is probably the most destructive process to which they are subjected.

The essential qualities which enable any material to withstand the wearing action of traffic are hardness and toughness. Laboratory tests have been devised for determining the relative degree in which these qualities are possessed by different kinds of stone and brick, but none of these tests is suitable for making similar determinations regarding concrete mixed in different proportions and composed of different materials. The reason for this is that the structure of concrete, unlike that of ordinary stone and brick, is not homogeneous. It is possible, however, to employ the routine road-material tests described in Office of Public Roads Bulletin No. 44 on the mortar and coarse aggregate separately, and it would seem that the results which might be obtained in this way ought to furnish a fairly reliable index to the quality of concrete which could be produced from the materials tested. The proper proportions in which to mix the materials can probably be best determined from actual service tests.

Plates VII, VIII, and IX are diagrams showing the relative hardness, toughness, and crushing strength of mortars mixed in different proportions and in which two different qualities of sand were used. Sand for one set of the test specimens, as noted on the diagrams, was standard Ottawa, while that for the other set was natural quartz sand which showed the following analysis:

TABLE I.—*Granulometric analysis of quartz sand.*[1]

Size of grains.	Grams.	Per cent.
Retained on—		
$\frac{1}{4}$-inch mesh screen	0.0	0.0
$\frac{1}{8}$-inch mesh screen	74.0	5.9
No. 10 screen	124.5	10.0
No. 20 screen	266.0	21.2
No. 30 screen	460.0	36.7
No. 40 screen	624.0	49.8
No. 50 screen	930.5	74.3
No. 80 screen	1,139.5	91.1
No. 100 screen	1,159.5	92.7
No. 200 screen	1,198.5	96.5
Passing a No. 200 screen	51.5	3.5
		100.0

[1] Total weight of sample, 1,250 grams; weight of sample after washing, 1,208 grams.

Experience has shown that when first-class sand is used very good results are obtained by using a proportion of 1 part of cement to $1\frac{1}{2}$ or $1\frac{3}{4}$ parts of sand and making the proportion of coarse aggregate such that the resulting concrete will contain slightly more mortar than is sufficient to fill all voids. If a well-graded gravel is used as coarse aggregate, the proportion should be about $1:1\frac{1}{2}:3$, while in most cases where broken stone is used as coarse aggregate it will be found desirable to make the proportion about $1:1\frac{3}{4}:3$, and in some cases, where the particles of stone are of uniform size, even a still greater proportion of mortar will be required, but this should be effected by decreasing the amount of coarse aggregate and not by further increasing the amount of sand.

Since the bottom course of a two-course pavement is not subjected to the wearing action of traffic, it would appear that the rules for proportioning the materials for this course might be considerably modified. On the other hand, using different proportions in the top and bottom courses undoubtedly results in the concrete of the two courses having different coefficients of expansion and different moduli of elasticity, and these differences might tend to cause a separation of the two courses. The fact that such separations sometimes occur strengthens this theoretical objection.

CONSTRUCTION.

TYPES.

There are two general types of concrete pavement, known as the one course and the two course. These designations are due to the fact that the former consists of one course of concrete, all of which is mixed in the same proportion and composed of the same kind of materials, while the latter consists of two courses of concrete, usually mixed in different proportions and containing different kinds of aggregate. Plate X, figure 1, shows a typical cross section for a

concrete pavement, and this general form is suitable for either one-course or two-course work. The one-course pavement is somewhat simpler to construct than the two-course type. It possesses the advantages that there is no possibility for the wearing surface to separate from the rest of the pavement, and that the resistance to wear should be uniform throughout the life of the pavement. Notwithstanding these advantages, local conditions may sometimes justify the two-course type of construction. For example, if the only materials locally available for use as aggregate were of very inferior quality, it might be more economical to use them for aggregate in the lower course of a two-course pavement and import aggregate for the wearing course than to employ a one-course pavement and import all the aggregate. The two-course pavement also requires slightly less cement per square yard than the one-course type if different proportions are used in the top and bottom courses; but this factor alone would seldom, if ever, justify a preference for the former type, especially in view of the objections to this method of construction, already noted.

Besides the two general types of concrete pavement described above, there are several special patented types, but so far as is known these do not possess any particular advantages and will not be discussed in detail. The one-course pavement is believed to be better adapted to most ordinary conditions than any other type of concrete pavement and will be given principal consideration in the following discussion.

Plates I to IV are arranged in logical sequence, to show the various steps in the construction of a one-course concrete pavement and are intended to supplement the descriptions of construction methods given below.

GRADING AND PREPARING THE SUBGRADE.

In forming a roadbed upon which a concrete pavement is to be constructed, the features which should receive primary consideration are (1) adequate drainage, (2) firmness, and (3) uniformity in grade and cross section.

It is impracticable to prescribe definite methods for securing thorough drainage which would be applicable to every location. The local conditions which affect the accumulation and "run-off" of both surface and ground water vary considerably even in the same locality, and it is only by means of a careful study of these conditions that a satisfactory system of drainage can be devised. For example, if the material composing the roadbed consists of springy earth, either tile or French drains would probably be necessary. In another case extremely flat topography may make it necessary to elevate the grade, by means of an embankment, considerably above the level of the ad-

FIG. 1.—PREPARING SUBGRADE.

FIG. 2.—SAND AND GRAVEL PILED ON SUBGRADE READY FOR USE.

EXPERIMENTAL CONCRETE ROAD, CHEVY CHASE, MD.

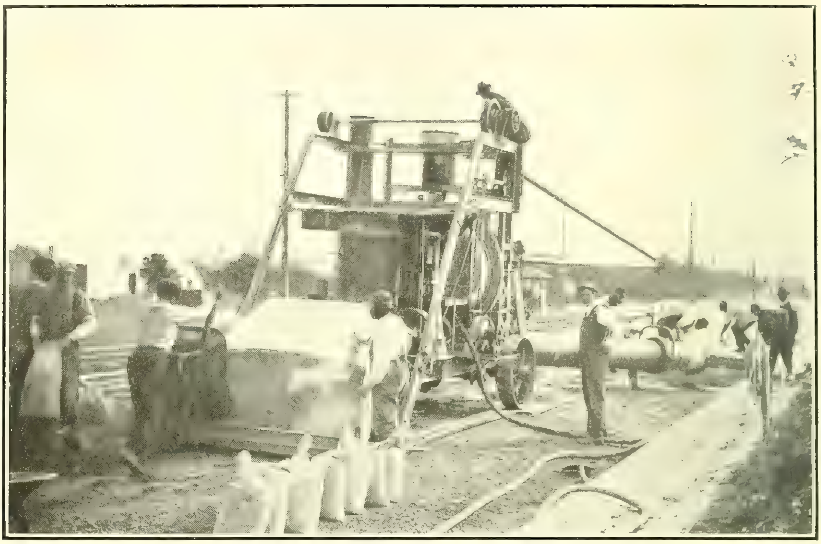


FIG. 1.—CHARGING CONCRETE MIXER.

FIG. 2.—PLACING CONCRETE AND USING TEMPLATE.

EXPERIMENTAL CONCRETE ROAD, CHEVY CHASE, MD.

FIG. 1.—FINISHING THE SURFACE WITH A WOODEN FLOAT.

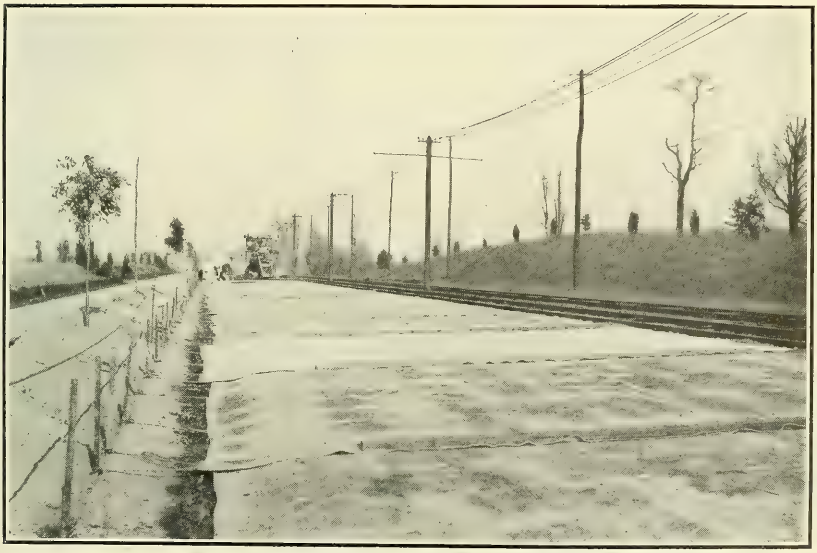


FIG. 2.—CANVAS COVERING IN PLACE.

EXPERIMENTAL CONCRETE ROAD, CHEVY CHASE, MD.

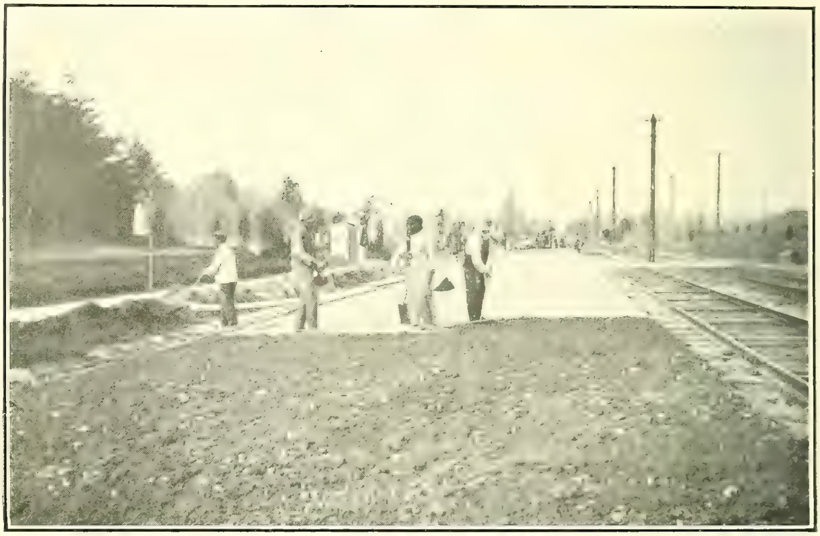


FIG. 1.—COVERING THE SURFACE WITH A LAYER OF EARTH AFTER CANVAS IS REMOVED.

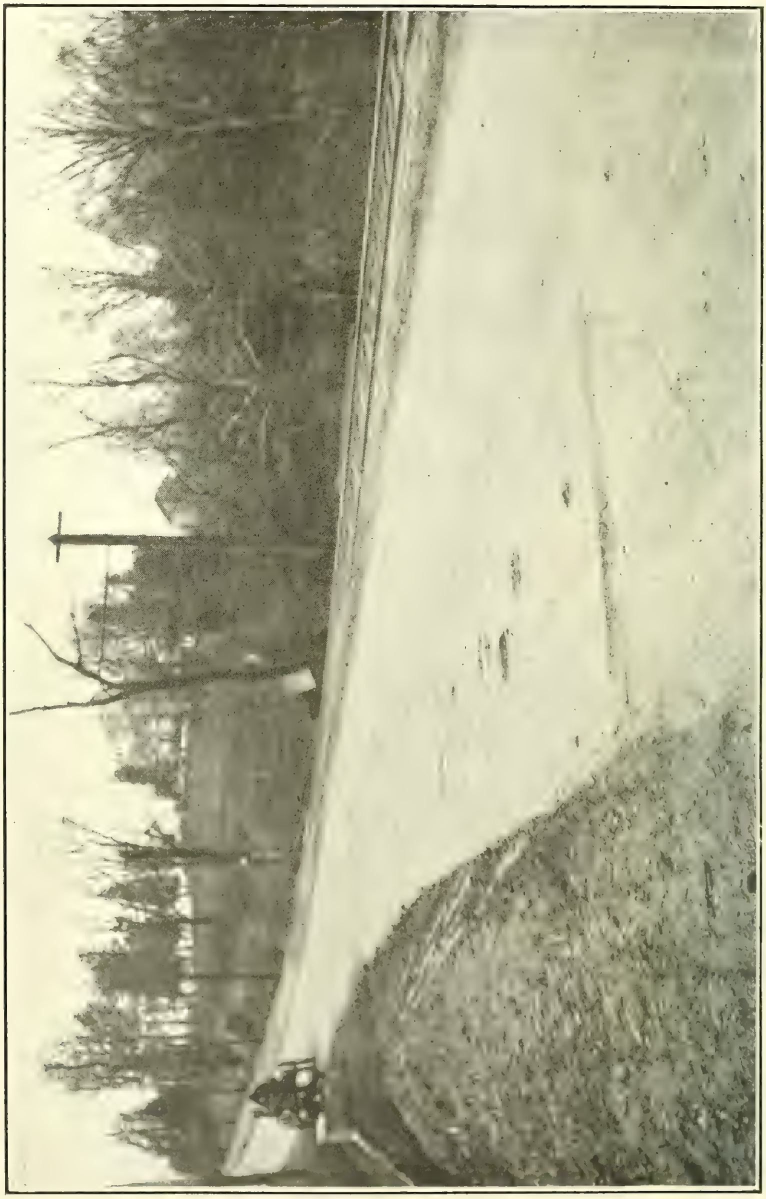
FIG. 2.—AFTER NEARLY TWO YEARS' SERVICE.

EXPERIMENTAL CONCRETE ROAD, CHEVY CHASE, MD.

FIG. 1.—BITUMINOUS WEARING SURFACE IN FAIR CONDITION AFTER ABOUT ONE YEAR'S SERVICE.

FIG. 2.—SHOWING UNSATISFACTORY CONDITION OF BITUMINOUS WEARING SURFACE AFTER LESS THAN ONE YEAR'S SERVICE.

EXPERIMENTAL CONCRETE ROAD, CHEVY CHASE, MD.



FAILURE OF CONCRETE PAVEMENT CAUSED BY SETTLEMENT OF EMBANKMENT.

jacent land. The nature of the soil, the character of the topography, and the amount and rate of rainfall must all be taken into consideration, if a system of drainage is to be properly planned.

The second requirement, firmness, can be secured only after the road has been properly drained. Soils which readily absorb moisture will not remain firm in wet weather and therefore should not be permitted to form a part of the roadbed, especially if they occur in the subgrade. This requirement also makes it necessary that the roadbed be thoroughly compacted. In forming embankments the material should be put down in layers not more than about 12 inches thick, and each layer should be thoroughly rolled. (See Pl. VI.) The subgrade in both excavation and embankment should be brought to its final shape by means of picks and shovels and rolling.

The cross section of the subgrade may be either flat or shaped to conform with the finished surface of the pavement. The flat cross section involves the use of a slight additional quantity of concrete, but gives an increased thickness at the center, where maximum strength is required. It has been observed that longitudinal cracks occur less frequently in concrete pavements laid on a flat subgrade than where the subgrade is curved to conform to the surface of a crowned pavement.

In either case the subgrade when completed should be uniform in grade, cross section, and firmness, not only to prevent a waste of concrete in filling up depressions but in order to facilitate the necessary movement of the pavement due to contraction and expansion and thus reduce its tendency to crack. The subgrade should be rolled and reshaped until the specified shape is secured. The forms, which should be set before the final shaping, may be made to serve as a guide for this work.

USE OF SUB-BASE.

Where old pavements which have been constructed on a sub-base are replaced by concrete pavements, it is frequently convenient to place the new pavements on the old sub-base. Furthermore, soil conditions are sometimes such as to make the use of a sub-base very desirable. This is especially true of soils which do not compact readily under the roller or which can not be effectively drained at a reasonable cost.

A satisfactory sub-base may be constructed of gravel, broken stone, telford, cinders, or any other similar material. The essential features in every case are firmness, smoothness, and uniformity in grade and cross section. Telford is seldom employed as a sub-base for concrete pavements, except when old macadam roads having such sub-bases are being repaved with concrete. When this is the case it would seem advisable to spread a layer of sand or other fine material over the sub-

base before the concrete is placed. Otherwise the irregularities in the telford surface would prevent the pavement from contracting and expanding readily and would thus cause cracks to occur at frequent intervals.

When old macadam or gravel roads are to be surfaced with concrete it is advisable to scarify the entire surface to a depth of several inches before the subgrade is shaped to receive the concrete. If this is not done, it is almost impossible to prevent a lack of uniformity in the subgrade wherever it is necessary to grade or shape up any part of the old road.

It has been suggested, with an apparent show of reason, that a thin cushion of sand might be advantageously used under concrete pavements. The purpose of this construction is to facilitate the sliding of the pavement, due to expansion and contraction, and thus to increase the allowable distance between contraction joints. So far as is known there are no experimental data which bear on this subject.

FORMS.

The form work required for concrete pavements is very simple and inexpensive. Ordinarily the forms may consist of 2½-inch boards having a width equal to the edge thickness of the pavement, though metal forms are in general more economical and are always to be preferred. The forms should be set before the subgrade is finished, in order to serve as a guide for the finish grading, and should be securely held in place by means of stakes driven on the shoulder side to such depth that they do not extend above the top of the forms. Care should be taken to see that the forms bear uniformly on the subgrade, as otherwise they are likely to sag while the concrete is being struck off and tamped, and thus produce an irregular surface. It is also well to have the ends of the different sections fastened together in such a manner that no relative displacement is possible.

The forms should always be set true to line and grade, and where curbs or gutters are to be provided they must be modified to suit the requirements for these features.

MIXING AND PLACING THE CONCRETE.

When a considerable area of concrete pavement is to be laid it is usually economical to employ a mechanical mixer for mixing the concrete (Pl. II, fig. 1). Hand mixing is much more expensive than machine mixing, and hand-mixed concrete is rarely as uniform as machine-mixed concrete either in consistency or in the distribution of the component materials. Since lack of uniformity is believed to be one of the most potent causes for the formation of cracks, machine mixing is greatly to be preferred. There are several makes

of machine mixers which have proved to be satisfactory for such work. The self-propelled batch type with a distributing device is probably the most economical to use where the amount of work to be done is sufficient to warrant the purchase of such a machine.

The distributing device may consist of a bucket and boom attachment or of a chute or a revolving tube which conveys the concrete from the drum of the mixer to its place in the road. The chute is objectionable, because if the concrete is mixed to such a consistency that it will readily flow down the chute it is too wet for best results; and, furthermore, there is a tendency for the mortar to separate from the coarse aggregate. This is especially true when the mixer is working down a steep grade. No matter what kind of distributing device is used, however, steep grades are liable to interfere with the proper working of the mixer, and if such grades occur on any particular piece of work that is to be undertaken this point should be investigated before the concrete mixer is purchased.

Even when the very best type of concrete mixer is employed it is necessary to exercise considerable care to see that the concrete is mixed thoroughly and to a uniform consistency. Tests have shown that increasing the time during which a batch of concrete remains in the revolving drum of a mixer, within reasonable limits, has very much the same effect as increasing the proportion of cement. It is also almost certain that varying amounts of water in successive batches will tend to cause cracks to develop in the pavement. It is impracticable to state definite rules for determining the number of turns of the mixer drum or the exact quantity of water which each batch should be given, because these features are considerably affected by the condition of the mixer and the materials. In general it may be said that each batch should be mixed until there are no uncoated particles of sand or coarse aggregate remaining, and the amount of water should be such that the resulting concrete will be quaky or jellylike, but not sufficiently wet to flow readily while it is being handled. On steep grades somewhat less water should be used in mixing the concrete than when the grade is level. A comparatively wet concrete is easier to handle on level grades, but is liable to flow on steep grades after the pavement has been struck off and tamped, causing irregularities to develop in the surface.

Immediately after the concrete is mixed it should be deposited in the pavement. Otherwise the materials of which it is composed will begin to separate, and if it is permitted to stand an appreciable length of time before being placed the heavy materials will settle to the bottom of the containing vessel, so that when it is emptied a core will be formed in the center of the space occupied by the batch. Concrete mixed in a stationary mixer and hauled to its place in the road is especially subject to this objection.

Before any concrete is placed the subgrade should be thoroughly sprinkled with water or a part of the water contained in the concrete will be absorbed by the subgrade, which may interfere with the process of setting.

For one-course work the concrete should be deposited between the forms in such quantity that when it is struck off and compacted it will present a uniform surface and have the depth required for the finished pavement. Each batch of concrete should be dumped as nearly in place as is practicable and should preferably be spread by means of mortar hoes. The men who do the spreading should avoid walking in the concrete, because each time the foot sinks into it the coarse aggregate is shoved down, and when the foot is withdrawn the space thus left tends to fill with mortar, which causes a lack of uniformity in the concrete.

After the concrete has been spread approximately to the required cross section it should be struck off with a strike board having slightly more crown than the cross section of the road. This allows for a slight amount of settlement when the concrete is compacted. The compacting should be done with a tamper shaped to conform with the cross section of the road and operated by two men, one standing on each side of the pavement. Suitable designs for strike boards are shown in Plate X, figures 2 and 3. The heavier design (Pl. X, fig. 3), on account of its durability, is especially adapted for use where a considerable amount of work is to be done. It is also in general somewhat more satisfactory than the light design on account of its greater rigidity. Plate X, figure 4 shows a design for a tamper made of steel which has been used very satisfactorily for compacting concrete after it has been struck off, and which is very rigid and durable.

Sometimes the tamping and striking off are done with the same template, but this is not altogether satisfactory, because when this is done it is impracticable for the template to have a greater crown than is required for the finished pavement, and it is difficult to strike off the concrete with such a template and at the same time make provision for compacting.

In the case of two-course pavements it is important that the top course be placed before the concrete in the bottom course has taken its initial set. The bottom course should be well compacted and struck off, but the striking off need not be as carefully done as in the case of the top course. The top course should be constructed in a manner similar to that described for one-course pavements.

FINISHING THE SURFACE.

The surface of a concrete pavement may be given either a rough or a smooth finish. A slightly roughened surface has the advantage of

being less slippery when the pavement is first constructed and is preferred by some engineers on that account. Smooth surfaces are more generally preferred, except on very steep grades, where it is sometimes desirable to provide grooves or other comparatively deep markings at right angles to the direction of traffic in order to afford a better foothold for horses. Such grooves, however, will cause rapid deterioration of the pavement under heavy traffic.

A satisfactory method of finishing the surface is to use a wooden float for smoothing out all template markings (Pl. III, fig. 1) and evening up other slight irregularities. This method of finishing produces a surface sufficiently rough for all ordinary grades and possesses the advantage of being extremely simple. In using the float special care must be exercised to keep the pressure of the hand uniform, in order not to produce irregularities in the surface. Wherever a depression occurs it should be filled by adding concrete, and not by raking mortar into it with the float. The workmen who do the floating should be provided with one or more light bridges, which span the pavement and which can be easily moved as the work progresses. Various sizes of floats are used, and provided they are handled by skilled workmen the size is not important. The long float shown in Plate X, figure 5, requires less skill on the part of the operators than short floats. A suitable design for a finishing bridge is shown in Plate XI, figure 1.

JOINTS.

It is customary to provide transverse joints at regular intervals in concrete pavements, to prevent irregular cracks from being produced; and if the width of the pavement exceeds 20 feet, longitudinal joints are also usually provided. Concrete contracts and expands with changes in temperature and also with changes in its moisture content. It also shrinks or contracts upon setting; and since the strength of the concrete is then comparatively low, the tensile stresses developed are much more likely to produce cracks than equivalent stresses developed in older concrete. It is evident that the greatest longitudinal stress which can be developed at any section of the pavement, due to contraction, is equal to the weight of the pavement, included between the section under consideration and the nearest free end, multiplied by the coefficient of friction between the pavement and the subgrade. Therefore, if contraction joints are spaced sufficiently close together to prevent this stress from exceeding the tensile strength of the concrete, no cracks should occur.

If no transverse joints are constructed in the pavement, the length of the sections between cracks, judging from such limited data as are at present available, will vary from 20 to 150 feet, and depends upon the kind of aggregate used, the relative richness of the concrete, the

condition of the subgrade at the time the concrete is placed upon it, and the method employed in curing the concrete. It is common practice to space the transverse joints from 25 to 50 feet.

If there were no curves in the alignment, or summits in the grade of a road, it is doubtful if any provision for expansion would be necessary in constructing the joints, because the elasticity of the concrete should be sufficient to take care of the expansion caused by changes in temperature and moisture content. In nearly all cases, however, there are curves in alignment and changes in grade which might permit a displacement of the pavement before a very high compressive stress was developed. For this reason it is advisable that joints be constructed to provide for a slight amount of expansion as well as for contraction.

There are a number of different methods of constructing joints, but none of them appear to be entirely satisfactory from every standpoint. Probably the simplest type of joint is that made by introducing into the pavement a board about five-eighths inch thick and shaped to conform with the cross section. This board is held in place by means of stakes until the concrete is placed against it on both sides. The stakes are then removed and the board is left in place with its upper edge even with the surface of the pavement and its lower edge resting upon the subgrade. The principal objections to this joint are that the board wears rather rapidly and does not protect the adjacent edges of the concrete.

A second method is to form a plane of weakness by placing a board so that its top edge is about 3 inches below the surface of the pavement. Then, when the contraction of the concrete has caused a crack to form immediately over the board, the crack is filled with bituminous material. This joint is said to have proved very satisfactory for dense concrete where the distance between joints is comparatively small, but it is subject to the objection that compressive stresses developed by expansion of the concrete are likely to be concentrated in the upper part of the pavement and to cause spalling at the joints.

Another method is to use a board, such as that first described, which is removed before the concrete has taken its final set. The opening thus left is later filled with bituminous material. The principal difficulty with this method is that when the board is withdrawn the adjacent edges of the concrete are usually disturbed and a rough joint is produced.

Probably the method most often used in constructing joints is to separate the successive sections of the pavement by means of specially prepared bituminous felt boards. These are usually held in place by means of properly shaped steel templates until the concrete is deposited against them, after which the templates are removed and the concrete flows around the boards. The thickness of this

joint has varied in common practice from one thickness of two-ply tar paper up to about one-half inch. A thickness of one-quarter inch seems to give very satisfactory results when the joints are spaced about 30 feet apart. Joints of this kind are sometimes provided with metal armor, which is intended to keep the adjacent edges of the concrete from being spalled off. It is claimed that armored joints require less maintenance than other types, but they are more expensive to construct.

The joints are undoubtedly the weakest feature of the concrete pavement; and no matter what type of joint is used, they must be given frequent and careful attention to prevent rapid deterioration of the pavement adjacent to them.

In the past, contraction joints of all types have usually been placed at right angles to the line of the pavement. This method of construction has the disadvantage that two wheels of a vehicle strike the joint at the same time and thus produce the maximum amount of impact. By skewing the joint at an angle of about 15 degrees the wheels strike one at a time, and the total resultant impact is reduced by at least one-half. This is advantageous to both the traffic and the pavement, and since the difficulties involved in constructing skewed joints are not at all serious. there is no apparent objection to their use.

PROTECTING AND CURING THE CONCRETE.

The quality of the concrete depends to a great extent upon the conditions under which it sets or hardens. When early exposed to dry air, for example, water is evaporated out, thereby greatly accelerating the shrinkage of the concrete and delaying the process of setting. It is evident that these results form a very effective combination for producing cracks. The effect of freezing on concrete is still more harmful; not only are cracks produced, but the internal structure of the concrete is also damaged.

The precautions that must be taken in order to protect a newly constructed concrete pavement during the process of curing depend largely on the weather conditions. In drying weather small hair-like cracks will frequently begin to form almost as soon as the surface of the concrete is finished, and unless the concrete is quickly covered and protected from the air these cracks increase in size very rapidly. At other times, when the atmosphere is moist, the concrete may sometimes be permitted to stand for several hours before being covered, without any danger of cracks forming. Heavy canvas made into sections of convenient length and proper width should be used for covering the concrete surface (Pl. III, fig. 2). The canvas should be spread over the pavement as soon as this can be done without marring the surface. Under unfavorable

atmospheric conditions it is sometimes better to spread the canvas immediately after the surface is finished, even at the risk of marring the surface slightly, than to run the risk of having cracks develop in the pavement. The canvas should be sprinkled until thoroughly wet immediately after it is spread and should be kept wet until removed and replaced with an earth covering. Under ordinary weather conditions about 24 hours will be required for the concrete to set sufficiently hard not to be damaged by men walking upon it while covering it with earth. The canvas should therefore usually remain on the pavement about one full day. Immediately after the canvas is removed the pavement should be covered with a layer of earth about 2 inches thick, which should remain on the pavement and be kept constantly wet for a period of about two weeks. During this period the roadway should be kept entirely closed to traffic. If the weather conditions are favorable the concrete ought to be sufficiently strong to withstand traffic at the end of two weeks. In cold or otherwise unfavorable weather the earth covering should preferably be thicker than 2 inches and left in place for a longer period of time. No concrete should be laid during freezing weather, but if danger of freezing develops after the concrete is laid and before it sets, the first cover of canvas should be supplemented in some way in order to prevent damage to the pavement. This may be done by spreading over it a layer of straw, or by using two thicknesses of the canvas, if this is practicable.

The protection of the concrete is an extremely important feature of concrete-pavement construction. It is impossible to secure satisfactory results unless some such precautions as those described above are taken to prevent the concrete from drying out too rapidly after it is placed, and to insure that it sets up under uniformly favorable conditions.

THE USE OF REINFORCING STEEL.

Probably the most satisfactory method, in point of efficiency, yet devised for reducing the number of objectionable cracks in concrete pavements is that of employing steel reinforcement. The reinforcement usually consists of woven wire or some similar material, though there is no apparent reason why plain round or square rods might not be satisfactorily used. One-quarter-inch round rods embedded about 2 inches above the lower surface of the pavement and spaced about 12 inches center to center in both directions would seem sufficient to eliminate practically all objectionable cracking, provided proper joints were introduced at changes in the grade and at curves in the alignment. But any satisfactory system of reinforcement will probably add from 15 to 20 cents per square yard to the cost of the pavement, and this additional cost is no doubt responsible for the

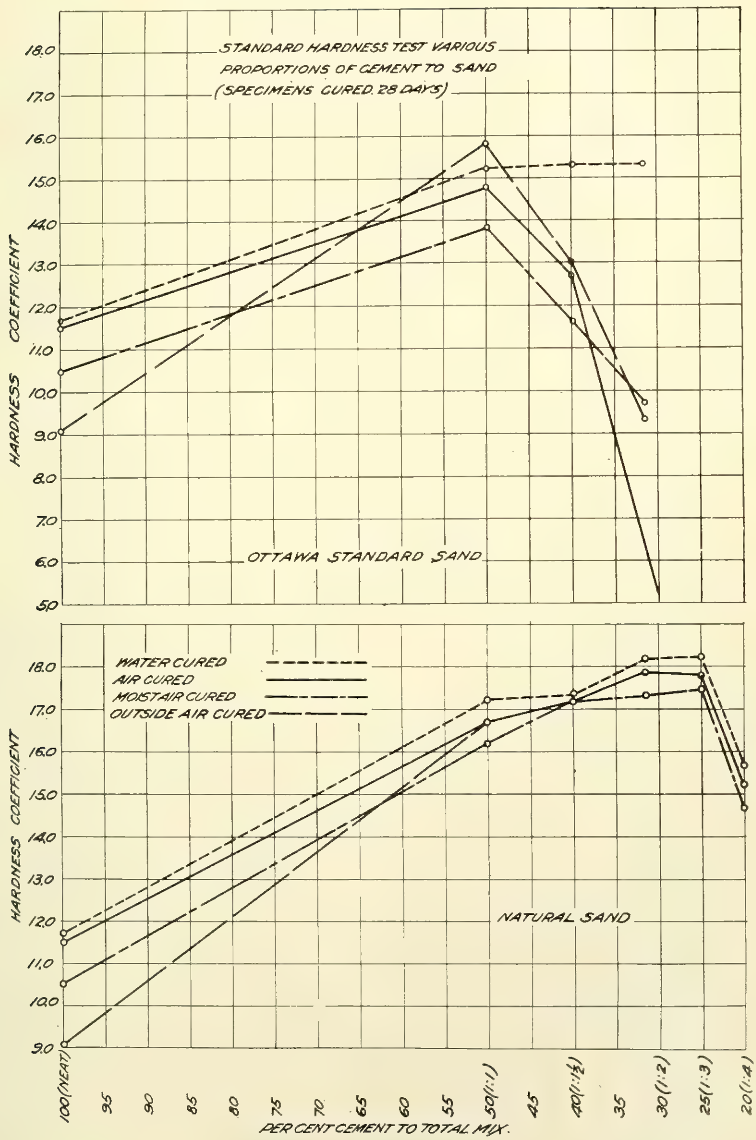


DIAGRAM SHOWING RESULTS OF HARDNESS TESTS OF CEMENT MORTARS.

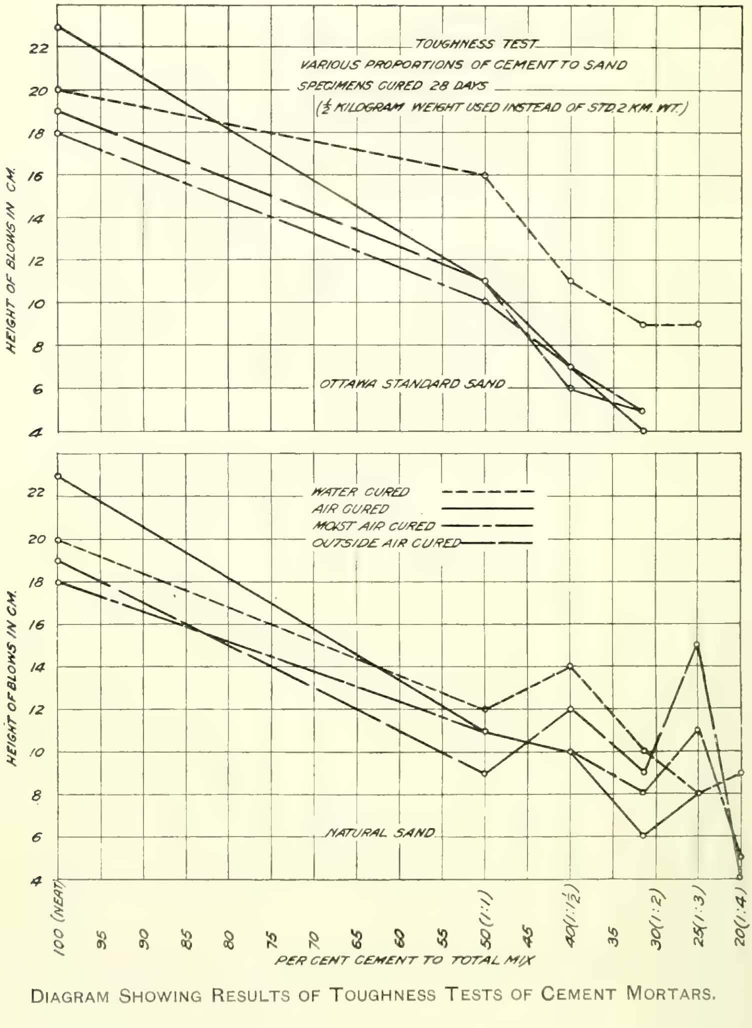


DIAGRAM SHOWING RESULTS OF TOUGHNESS TESTS OF CEMENT MORTARS.

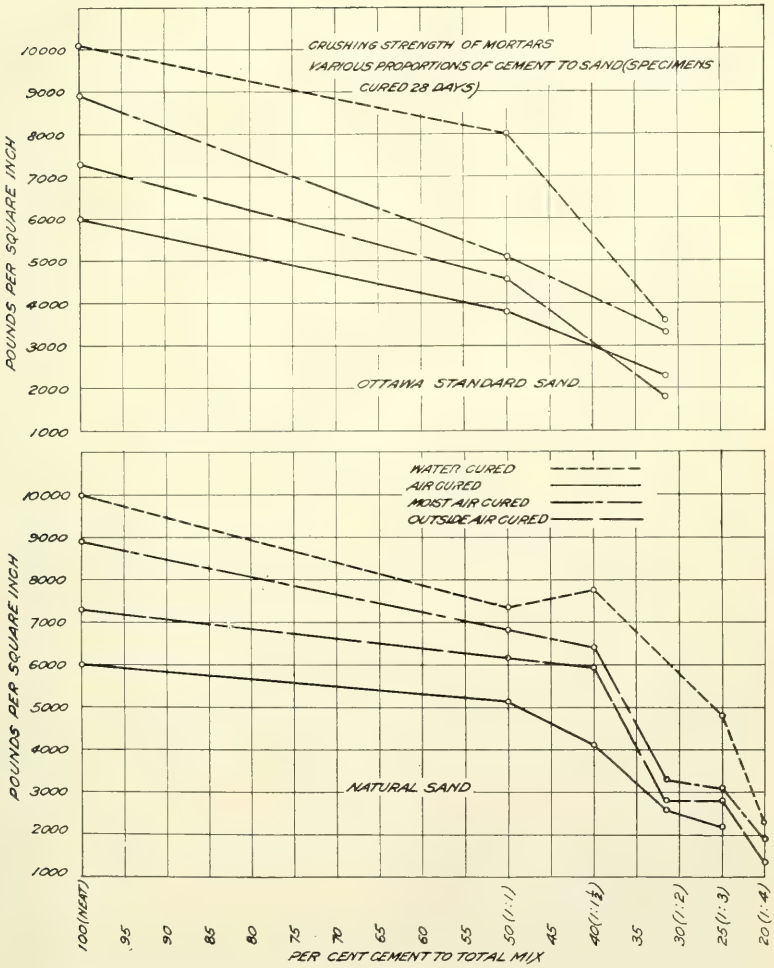


DIAGRAM SHOWING RESULTS OF CRUSHING STRENGTH TESTS OF CEMENT MORTARS.

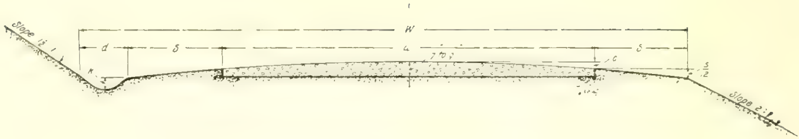


FIG. 1.—TYPICAL SECTION OF CONCRETE ROADWAY.

Side ditches should be of sufficient size to dispose of all drainage; C may vary from $\frac{w}{96}$ to $\frac{w}{72}$; when w exceeds 20 feet make joint in center and crown subgrade; k varies from 6 to 12 inches.

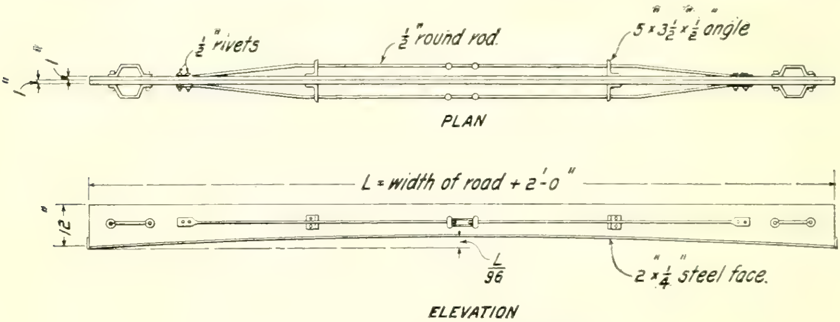


FIG. 2.—TYPICAL DESIGN FOR STRIKE BOARD.

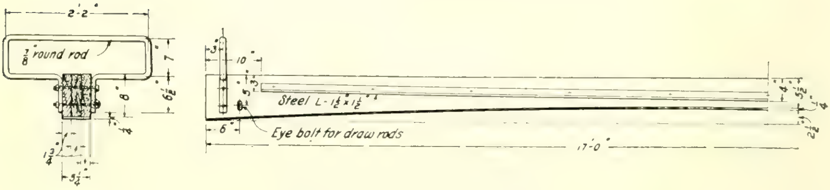


FIG. 3.—WOODEN STRIKE BOARD.

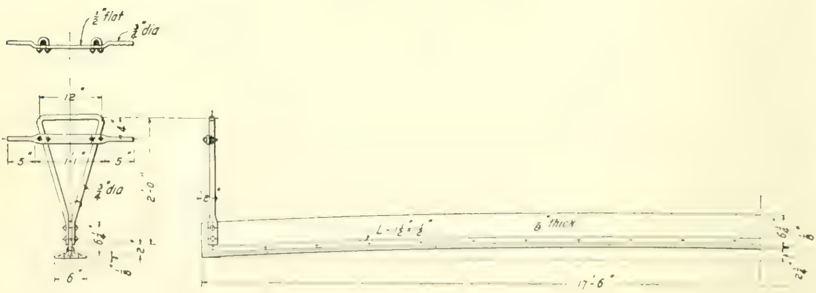


FIG. 4.—STEEL TAMPER.

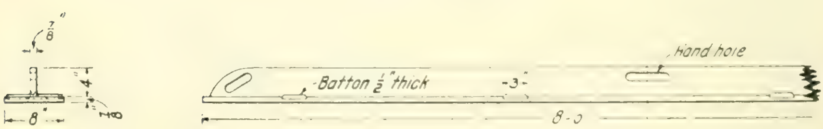


FIG. 5.—LONG WOODEN FLOAT.

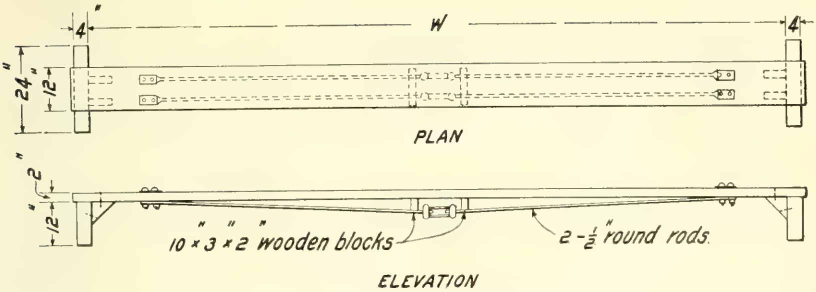


FIG. 1.—TYPICAL DESIGN FOR FINISHER'S BRIDGE.

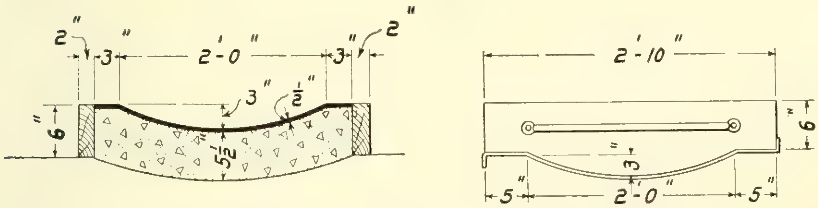


FIG. 2.—TYPICAL CROSS SECTION OF CONCRETE GUTTER AND DESIGN FOR A TEMPLATE TO BE USED IN ITS CONSTRUCTION.

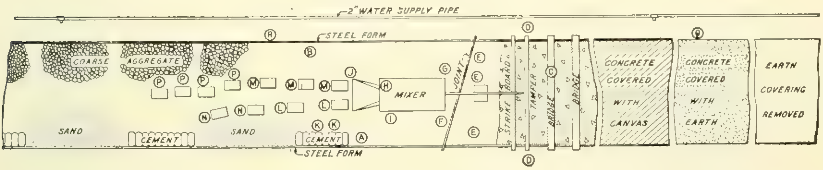


FIG. 3.—DIAGRAM SHOWING DISTRIBUTION OF FORCE, USING 2-BAG MIXER.

A, foreman; B, subforeman; C, finisher; D, 2 laborers striking and tamping; E, 3 laborers placing concrete and assisting in striking; F, mixer tender; G, laborer cleaning subgrade and setting joints; H, mixer engineer; I, fireman, also sprinkles subgrade; J, laborer assisting wheelers and cement handlers; K, 2 laborers handling cement; L, 2 laborers wheeling sand; M, 3 laborers wheeling coarse aggregate; N, 2 laborers loading sand; P, 4 laborers loading coarse aggregate; Q, laborer sprinkling pavement; R, water boy. Total, 2 foremen and 25 laborers. ▭ indicates wheelbarrow.

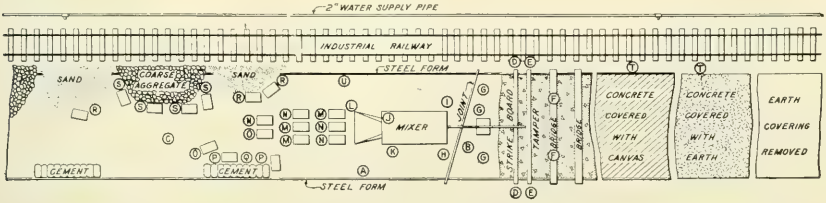


FIG. 4.—DIAGRAM SHOWING DISTRIBUTION OF FORCE, USING 3-BAG MIXER.

A, foreman; B, subforeman on placing concrete; C, subforeman on charging mixer; D, 2 laborers striking; E, 2 laborers tamping; F, 2 finishers; G, 3 laborers placing concrete; H, mixer tender; I, laborer cleaning subgrade and setting joints; J, mixer engineer; K, fireman, also sprinkles subgrade; L, laborer assisting wheelers; M, 3 laborers wheeling sand; N, 4 laborers wheeling coarse aggregate; O, 2 laborers wheeling cement; P, 2 laborers handling cement; Q, laborer opening bags; R, 3 laborers loading sand; S, 4 laborers loading coarse aggregate; T, 2 laborers sprinkling pavement; U, water boy. Total, 3 foremen and 36 laborers. ▭ indicates wheelbarrow.

fact that concrete pavements are seldom reinforced. Furthermore, reinforced pavements are more difficult to repair than those made of plain concrete, which may be a very serious objection under some circumstances.

GUTTERS.

It is frequently desirable to provide concrete pavements with paved gutters in order to prevent the side ditches from eroding. Plate XI, figure 2, shows a typical design for a concrete gutter. This design has been frequently used and has usually proved to be satisfactory. A suitable strike board for forming this gutter is also shown in the figure.

It is impracticable to construct the pavement and the gutter at the same time, and on account of the convenience of using the pavement as a platform for material and for mixing concrete for the gutter the pavement is usually constructed first. When there is no space between the gutter and pavement the joints should always be continued through both. If this is not done, the joints in each are apt to be continued as cracks in the other.

CURBS.

Concrete pavements on country roads are not generally provided with curbs, because it is usually desirable to use the shoulders as part of the roadway. Under some circumstances, however, curbs may be employed to advantage. For example, in deep cuts it might be justifiable economy to omit the shoulders and side ditches and provide curbs along the edges of the pavement so that the sides of the pavement would serve as gutters. Likewise, on very deep fills curbs are sometimes used to protect slopes from erosion. When this is done it is necessary to provide catch basins at low points in the grade.

BITUMINOUS WEARING SURFACE.

Since 1906 a number of experiments have been made in an effort to develop some satisfactory method of constructing a bituminous wearing surface on concrete pavements. Various kinds of bituminous materials have been used and several methods of applying them have been tried. Some of the surfaces are reported to have given moderately good service under light traffic, but in general they have not been durable where the traffic is at all heavy. The uneven manner in which they fail tends to produce excessive wear on portions of the concrete, and renewals should be made promptly as needed.

The principal advantages claimed for bituminous wearing surfaces on concrete pavements are:

(1) They make it possible to substitute continuous maintenance for periodic renewals of the pavement.

(2) They reduce the noise made by the impact of horses' hoofs and steel-tired wheels.

(3) They remove the principal objection to bituminous expansion and contraction joints.

(4) They overcome the somewhat objectionable glare of concrete pavements in strong light, though this objection may also be overcome with much less cost by sprinkling the pavement with crude water-gas tar.

The principal disadvantages may be inferred from what has already been said. It is also well to note that, where traffic conditions are such as to make a bituminous surface practicable on a concrete road, a bituminous-surfaced macadam road might also be practicable and would certainly be cheaper to construct, unless the difficulties involved in securing suitable stone for the macadam were very unusual.

In constructing bituminous surfaces on concrete it is essential to have the surface of the concrete entirely clean and free from laitance when the bitumen is spread. Generally about one-half gallon of bitumen to the square yard is put on in either one or two applications, by hand or by means of pressure distributors. It is sometimes swept with hand brooms in order to make it adhere better to the pavement. Hot applications have hitherto been almost exclusively used, though there is no apparent reason why materials which could be spread cold might not be employed with equally satisfactory results.

After the bitumen has been spread as described, it is covered with coarse sand, pea gravel, or stone chips, applied at the rate of 1 cubic yard to from 75 to 100 square yards of surface. The road may be opened to traffic almost immediately after the sand or stone chips are spread. Plate V shows the conditions of different concrete roads with bituminous wearing surfaces after certain periods of service.

It is realized that the above discussion of bituminous wearing surfaces falls very far short of furnishing a guide for undertaking work of that kind. The available data upon this subject, however, are not considered sufficient to form a basis for a more comprehensive discussion. Not only have contradictory results been reported by different engineers concerning the same methods of construction, but the results now being obtained from carefully conducted experiments by the Office of Public Roads with different materials and different construction methods do not yet seem to warrant any definite statements as to what materials are best adapted for such work nor which construction method will give the best results, though they do indicate in a general way that tars are preferable to asphalts for this purpose.

METHODS, ORGANIZATION, AND EQUIPMENT.

When it is considered that ordinarily from one-third to one-half of the total cost of constructing a concrete pavement is for the labor employed in doing the work after the materials are delivered, the importance of efficient organization, proper equipment, and economical methods becomes readily apparent. Failure to give these features proper consideration may easily result in adding from 10 to 20 per cent to the cost of a concrete pavement, and has no doubt frequently caused road contractors to sustain a net loss on projects of this kind, where profits might have been made.

It is not the province of this bulletin to furnish detailed rules for the guidance of contractors in planning and executing their work, but it seems desirable to discuss briefly a few important points which contractors and engineers in charge of force-account work should consider in connection with concrete-pavement construction. The points which are of most importance, and to which the discussion will be confined, are concerned with, first, the proper order and progress of the work; second, the economic handling of materials; and third, the amount of capital necessary to carry on such work economically.

ORDER AND PROGRESS OF THE WORK.

In constructing a concrete pavement it is especially desirable that the work of mixing and placing the concrete be as nearly continuous as practicable after it is once begun. Where the mixer is permitted to stand idle for even a few days the force of laborers employed in operating it will usually become more or less disorganized, and an appreciable amount of loss and unsatisfactory work will generally result when the mixing is resumed. On this account the order and progress of the work should ordinarily be planned with the primary view to keeping the mixer going full time every working day that the weather will permit. This means that ample provision should be made for completing the drainage structures, the grading, and the preparation of the subgrade well ahead of the mixer, as well as for supplying the mixer with all necessary materials.

The drainage structures should preferably be completed in advance of the grading in order to obviate the necessity for moving embankment material the second time. Where the concrete materials are to be hauled out by means of an industrial railway, however, it is usually impracticable to extend the railway ahead of the grading, and the saving effected in hauling the materials for the drainage structures on the industrial railway may justify permitting the grading to proceed ahead of the drainage structures.

Rather than construct a concrete culvert sufficiently far in advance for the subgrade to be prepared before the mixer arrives, it may sometimes be economical to leave out a section of the pavement over the culvert. But the extra expense involved in going back and putting in a section of this kind after the work of laying the pavement has progressed a considerable distance ahead is usually considerable and is often underestimated by contractors. This method of doing the work also involves a delay in opening the road, and as a rule is very objectionable on that account.

The work of preparing the subgrade and setting the forms should preferably proceed sufficiently far in advance of the mixer to allow for two or three days' run. The prepared subgrade, if properly drained, dries out much more rapidly after rains than the rough grade, and thus it is possible to resume the placing of concrete much earlier than when the roadbed has not been shaped and rolled. A soaking rain will usually cause the prepared subgrade to heave slightly and make rerolling necessary, but ordinarily this is a very small item.

OPERATING THE CONCRETE MIXER.

In general it is economical to employ a mixer of the street-paving type for mixing and placing the concrete, though in some cases it has proved satisfactory to do the mixing in stationary mixers and haul the concrete out to its place in the road. This latter method is applicable to relatively only a very few sets of conditions, however, and will therefore not be discussed in detail.

There are two sizes of street-paving mixers commonly used in concrete road construction. The smaller is capable of mixing a batch, of the proportions usually required, containing two bags of cement, and the larger will mix a batch containing three bags of cement. The larger size is economical where materials can be rapidly obtained and where the amount of work to be done is sufficient to warrant providing equipment for handling the materials necessary to keep the larger mixer running up to its capacity. Where the materials can be economically obtained only at a slow rate, or where the expense of providing facilities for handling large quantities of materials would be excessive, the smaller size of mixer is more economical to use. When efficiently operated, either size of mixer should ordinarily mix from 400 to 450 batches of concrete in a working day.

Organizing a force of laborers to operate a paving mixer efficiently requires considerable skill in handling men. The best results are generally obtained when a mixer is fully manned and each laborer is assigned definite work to perform.

The accompanying diagrams, Plate XI, figures 3 and 4, illustrate mixer organizations for the two sizes of mixers in general use, which

were worked out by a contractor of considerable experience. Laborers for preparing the subgrade, setting the forms, and for covering the concrete with earth should be provided in addition to those called for in the diagrams.

HANDLING MATERIALS.

One of the most difficult problems which has to be solved in connection with concrete road construction is that of determining the proper methods to employ in handling and delivering the materials for the concrete. The different kinds of material required must be delivered to the mixer in definite proportions at the same time, and it is evident that the location of the several sources from which the materials are obtained, with respect to each other and to the road, will have a very great influence in determining the most economical transportation methods.

Consider, for example, a project on which is used a concrete mixer of the street-paving type which mixes a batch containing three sacks of cement. If the work is to progress normally, the quantities of the different materials required each day will be approximately as follows:

Cement	barrels	320
Sand	cubic yards	70
Coarse aggregate	do	140
Water	gallons	8, 800

In addition to the above, if the mixer runs continuously, about 10,000 gallons of water will be required each day for keeping wet that part of the pavement which will have been laid during the two preceding weeks, and for sprinkling the subgrade before the concrete is placed. This makes the total weight of water which may be required each day about 75 tons, and the total weight of all the materials combined about 420 tons per day.

The importance of the water supply is not always appreciated by contractors and engineers, and the provision made for delivering water on the work has sometimes been entirely inadequate. Another frequent error is that of overestimating the amount of water which a chosen stream is capable of supplying. In general, the most practicable method of delivering the water is to pump it through a pipe line laid along the road. The pipe should be at least 2 inches in diameter, and for the mixer under consideration the pump should be capable of furnishing about 25,000 gallons of water in 10 hours to any point on the pipe line. Ordinarily at least 10,000 feet of pipe will be required if the concrete is to be sprinkled for two weeks after it is laid.

The proper method of handling the cement is sometimes considerably affected by the requirements which the specifications provide regarding tests. Some specifications require that the cement shall be held until the results of the 28-day test are reported, while others permit its use as soon as it has satisfactorily passed such tests as may be made within seven days. If any tests of consequence are required and the sampling is not done until the cement arrives at the nearest railroad station, it will be necessary either to unload and store it or pay demurrage charges. This difficulty may be overcome to some extent by placing an inspector at the cement plant to collect and forward samples to the testing laboratory as soon as the cars are loaded. The testing may then be begun while the cars are en route.

Another plan sometimes employed to lessen the demurrage and avoid rehandling is to purchase bin-tested cement and have the cars loaded under the supervision of an inspector. When this is done, the cement may be used as soon as it arrives on the work, but the custom of cement manufacturers to make a slight additional charge for bin-tested cement may entirely offset the economical advantages gained by its use.

No matter what the arrangements for testing the cement may be, provision should usually be made for storing near the work sufficient cement to keep the mixer going for four or five days, in case that shipments are delayed, as frequently happens.

In general, the most satisfactory method of hauling the materials for the concrete is by means of an industrial railway constructed along one shoulder of the road, though this method is not always the most economical. Teams, traction engines with trailers, and motor trucks with or without trailers have each been frequently used for this purpose, and are no doubt each economically best adapted to certain sets of conditions. But all of these are objectionable from a construction standpoint on account of the damage which they usually do to the subgrade.

Among the advantages possessed by an industrial railway for hauling the concrete materials are:

(1) Materials may be delivered without disturbing the subgrade.

(2) The railway may be readily operated along the shoulder of a newly laid pavement, which makes it practicable to prosecute the work at any desired point.

(3) Hauling is affected comparatively little by weather conditions.

(4) Where there is sufficient work to keep an industrial railway outfit busy, it is usually economical, especially where the size of the projects is such that the railway can be operated continuously throughout a season on the same project. The purchase of an industrial railway outfit, however, usually involves a greater outlay of capital than is desirable for a single project.

From a purely economical standpoint the choice of means for hauling the materials would probably be made about as follows:

First. Where the maximum haul does not exceed 3 miles and the amount of concrete to be laid does not exceed about 5,000 cubic yards, team haul would probably be economical.

Second. If the amount of concrete to be laid exceeds about 5,000 cubic yards, or if the maximum haul exceeds about 3 miles, and the materials are hauled in from the same direction, an industrial railway, tractors, or motor trucks may be economically used.

Third. Where the materials are hauled in from each end of the road, or where it is desired to operate more than one mixer at the same time, the industrial railway is usually more practical and economical.

Where the sand and coarse aggregate are shipped in by rail, the work of unloading the railroad cars and loading the wagons or cars in which the materials are to be hauled out to the work can usually be most economically done by means of machinery especially adapted to this kind of work. In order to avoid paying demurrage, and to have the materials on hand when they are needed, it is nearly always necessary to handle a considerable part of the materials the second time. Hence it may be desirable to have two sets of unloading and loading machinery in cases where the stock piles and bins are located out on the work instead of at the siding where the materials are delivered.

The kind of unloading and loading device to employ depends to a very great extent on the quantities of materials to be handled and the other conditions to be met. If the stock piles and bins are adjacent to the siding where the materials are delivered, and a considerable quantity of work is to be done, a locomotive crane may frequently be used to advantage, while, if the stock piles and bins are out on the work, it may be economical to handle the material at the siding with scrapers or similar devices and install an elevating device at the bins where the materials are stored. In other cases the extent of the work may not be sufficient to warrant any machinery whatever for handling the materials, in which event the handling may be rather expensive.

CAPITAL REQUIRED.

The amount of capital required to carry on concrete road construction successfully depends almost wholly on the size of the project and the circumstances under which the work is to be done. Where a considerable quantity of work is to be done in the same community it may be possible to keep a very elaborate equipment busy, even though the individual projects are comparatively small. On the other hand, it may be poor economy to provide more than the smallest practicable

equipment for a rather large project in a community where few other concrete roads are likely to be constructed.

The equipment necessary for handling and hauling the materials frequently represents a much greater outlay of capital than all other expenditures combined, but, as has already been pointed out in discussing the handling of materials, the conditions affecting this feature of the work are subject to great variation. A general discussion as to the cost of this part of the equipment, therefore, would usually be of small value in connection with any particular project and will not be undertaken.

The equipment necessary for doing the rough grading in connection with concrete road work is not essentially different from that required for grading other types of roads. Since the amount of capital necessary to provide grading equipment to suit various sets of conditions is familiar knowledge to practically all road engineers and contractors, this feature will not be discussed here.

The capital required to provide equipment for preparing the subgrade and mixing and placing the concrete depends on the rate at which it is purposed to carry on the work. The lists given below show the approximate cost of outfits using either a 2-bag or a 3-bag mixer.

Outfit No. 1 (2-bag mixer).

1 rooter plow	$50
1 road grader	300
1 heavy 4-horse plow	30
Shovels, picks, and other small tools	75
1 10-ton macadam-type road roller	2,500
1,800 feet of steel forms, complete with stakes, etc	200
1 pump and engine capable of delivering at least 1,500 gallons of water per hour	175
10,000 feet of 2-inch wrought-iron water pipe, with valves every 200 feet	950
400 feet of rubber hose, with couplings	80
12 wheelbarrows	60
1 concrete mixer, with skip and distributing device	1,600
Strike board, tamper, mortar hoes, sledges, etc	100
Total	6,120

Outfit No. 2 (3-bag mixer).

1 rooter plow	$50
1 road grader	300
1 heavy 4-horse plow	30
Shovels, picks, and other small tools	100
1 10-ton macadam-type road roller	2,500
3,000 feet of steel forms, complete with stakes, etc	325
1 pump and engine capable of delivering at least 2,500 gallons of water per hour	300
10,000 feet of 2-inch wrought-iron water pipe, with valves every 200 feet	950

600 feet of rubber hose, with couplings	$120
20 wheelbarrows	100
1 concrete mixer, with skip and distributing device	2,000
Strike board, tamper, mortar hoes, sledges, etc	100
Total	6,875

Ordinarily the method of paying for the work should enable the contractor to meet most of his bills for labor and materials after the first one or two estimates, so that the total amount of capital required for carrying on the work need not greatly exceed the cost of the equipment. For the average small project, where no very elaborate equipment is required to handle the materials, it seems that a total working capital of about $10,000 should be sufficient.

COST OF CONCRETE PAVEMENTS.

The cost of concrete pavements is almost wholly dependent on local conditions, and the conditions are seldom exactly the same, even for two projects in the same locality. It is therefore evident that a tabulation of cost figures for projects which have already been completed would be of little service in estimating the cost of new work, unless the conditions which affected the cost of the completed work could be fully compared with those under which the proposed work is to be done. Furthermore, some of the conditions which affect the cost of work are extremely uncertain. Among these are the weather, the efficiency of labor, and what is commonly called the element of luck. These may all influence the cost of a project to a considerable extent, but their influence can seldom be expressed in definite figures.

The most satisfactory method of arriving at the probable cost of a proposed pavement is first to ascertain by careful measurements and computations the quantities of the materials to be used and the various kinds of work to be done. An itemized estimate based on these quantities and the unit costs which prevail in the community for such materials and work may then be made. To this estimate should ordinarily be added a reasonable amount to cover unforeseen contingencies, and, also, if the work is to be done by contract, a fair profit for the contractor. From 15 to 20 per cent of the estimated cost is usually considered sufficient to cover these items.

In order to appreciate the importance of considering the different items separately in preparing an estimate of cost, it is necessary only to consider briefly the great amount of variation in unit costs.

The grading is usually paid for by the cubic yard of excavation, and the cost varies not only with the quantity but is greatly influenced by the character of the soil. In light, easily loosened soils grading may usually be done at from 25 to 40 cents per cubic yard. In hard earth containing more or less loose rock the cost per cubic yard gen-

erally varies from 40 to 75 cents, while grading in solid rock may sometimes cost as much as $1.50 per cubic yard. It is well to consider the cost of the rough grading entirely apart from the cost of the pavement. The drainage structures, however, may be considered together with the grading. The cost of these varies over such a wide range that no attempt will be made to discuss them here.

The cost of shaping and rolling the subgrade after the rough grading is completed is generally from 5 to 10 cents per square yard. This cost should be included with the other items which make up the cost of the pavement proper.

The cost of the concrete depends largely on the cost of the materials of which it is composed. These materials, delivered on the work, vary in cost according to the location of the work and the freight rates about as follows: Cement, from $1 to $2.50 per barrel; sand, from $0.60 to $2 per cubic yard; and broken stone or gravel, from $0.60 to $2 per cubic yard. The cost of mixing, placing, and finishing the concrete ordinarily varies from $0.60 to $1.25 per cubic yard, and depends on the efficiency of the organization and on whether the mixing is done by hand or machine. For machine mixing and labor at $0.20 per hour, $0.80 appears to be a fair average cost per cubic yard, including all overhead and incidental charges. The cost of constructing forms, contraction joints, etc., including the materials, is usually from $0.03 to $0.10 per square yard. Where simple types of joints and forms are used this cost should not exceed about $0.05 per square yard of pavement.

The following actual cost records taken from the 1912 annual reports of the Illinois State Highway Commission should prove helpful in estimating the cost of new work. These records do not appear to include any charges for the use of tools and machinery, but such charges should properly be included in preparing an estimate.

TABLE II.—*Cost of concrete roads in Illinois.*

Labor and supplies.	Project No. 1.		Project No. 2.		Project No. 3.	
	Totals.	Per square yard.	Totals.	Per square yard.	Totals.	Per square yard.
Superintendence	$140.00	$0.028	$157.50	$0.0220	$202.00	$0.0361
Shaping subgrade	307.41	.061	108.70	.0153	232.44	.0415
Loading and hauling sand and stone	267.34	.053	795.05	.1120	603.50	.1078
Mixing and placing concrete	414.63	.083	700.58	.0986	644.25	.1150
Watchman and miscellaneous labor	110.26	.022	131.46	.0184	383.75	.0686
Cost of sand and stone	1,017.63	.204	741.00	.1050	1,622.01	.2897
Cost of cement	1,547.15	.309	2,307.90	.3246	1,551.17	.2772
Expansion joints	48.67	.010	112.40	.0156	206.74	.0369
Coal and oil for mixer, and miscellaneous supplies	30.75	.006	25.00	.0034	119.19	.0213
Forms and other lumber	35.00	.007	31.75	.0047	18.33	.0033
Filling expansion joints next to curbs	45.18	.010				
Reinforcing steel			100.00	.0140		
Excavation			591.73	.0840		
Trimming shoulders					211.38	.0378
Totals	3,964.02	.793	5,803.07	.8176	5,794.76	1.0352

Dimensions of pavements, length of haul for materials, and cost of cement and amount used per square yard.

Project No. 1:

Area of pavement laid	square yards	5,000
Thickness of pavement	inches	6
Width of pavement	feet	45
Length of haul for materials	mile	$\frac{1}{8}$
Cost of cement per barrel	dollars	1.06
Amount of cement used per square yard	barrel	.29

This is a one-course pavement for which the coarse aggregate was gravel mixed with a small amount of Joliet crushed stone. The conditions under which the pavement was constructed appear to have been favorable. The cost is low.

Project No. 2:

Area of pavement laid	square yards	7,111
Thickness of pavement	inches	$6\frac{1}{2}$
Width of pavement	feet	16
Length of haul for materials	miles	$1\frac{1}{2}$
Cost of cement per barrel	dollar	.98
Amount of cement used per square yard	barrel	.33

This is a one-course pavement. The sand and crushed stone were both obtained free and the only charges were for freight. A newly filled sewer trench made it necessary to cross-reinforce a small part of the pavement with $\frac{1}{2}$-inch square twisted bars, 6 feet long and 12 inches center to center. The cost of this section, exclusive of grading, was only $0.7336 per square yard. This low cost was largely due to the free sand and crushed stone.

Project No. 3:

Area of pavement laid	square yards	5,594
Thickness of pavement	inches	7
Width of pavement	feet	18
Length of haul for materials	mile	$\frac{1}{8}$
Cost of cement per barrel	dollars	1.025
Amount of cement used per square yard	barrel	.29

This is a one-course pavement, and the coarse aggregate consisted of gravel. Armored expansion joints were used. The thickness varies from 8 inches at the center to 6 inches at the side. Congestion of traffic caused some expense and delay. The cost, however, is only moderate.

MAINTENANCE.

The shoulders, slopes, and drainage structures of concrete roads require the same kind of maintenance as other types of improved roads and will, therefore, not be given special attention here. The maintenance of the pavement consists, for the most part, in repairing cup holes, cracks, contraction joints, and perhaps the renewal of an occasional defective area.

Cup holes are spots in the surface of the pavement which break down under traffic and which may result from any one of a number of causes. The most frequent cause for such defects is the presence

of sticks, lumps of clay, particles of unsound stone, or other objectionable material in the aggregates. When cup holes first appear they are usually from 1 to 2 inches in diameter and from ½ to 1 inch in depth, but they become gradually enlarged by the action of traffic in loosening and abrading the concrete around their edges, and unless promptly repaired they may soon have an area of several square feet and a considerable depth. The action of traffic also gradually breaks away the concrete at the edges of cracks and joints, and if proper maintenance is not provided a considerable area of the surface of the pavement will be destroyed. The maintenance of cup holes, cracks, and joints usually consists of filling them with tar and covering the tar with coarse sand, pea gravel, or stone chips. Satisfactory results can be secured by this method only when a crew with proper equipment and materials goes over the road making necessary repairs at least two or three times a year.

Where defects of any considerable size are to be repaired the edges should be chiseled down until they are approximately vertical and not less than about 1 inch deep. The hole should be thoroughly cleaned and painted with tar, after which it should be filled with clean, coarse stone chips thoroughly grouted with tar. The surface of the patch should then be covered with coarse sand, pea gravel, or fine stone chips.

Either refined water-gas or coal-gas tar may be used for making such repairs, and the Office of Public Roads has obtained satisfactory results with both kinds. There is some difference of opinion among engineers as to just what consistency the tar should possess in order to give the best results, but the most general requirement in this particular seems to be that the tar when subjected to the float test in water at 50° C. will permit the float to sink in about 100 seconds. In order to apply a tar of this kind satisfactorily it is necessary that it be heated to about 225° F.

The repair equipment may consist of a small portable tar kettle, a horse and cart, pouring pots, wire brooms, hammers, and stone chisels.

When it becomes necessary to renew any portion of the pavement with Portland cement concrete that portion should be entirely closed to traffic, and the concrete should be mixed, placed, and cured in the manner described in the discussion of construction. The edges of the old concrete should be thoroughly cleaned and coated with neat cement mortar before the new concrete is placed.

A properly constructed concrete pavement ought to wear down uniformly and develop few defects. Poorly constructed and poorly maintained contraction joints are probably responsible for more defects of the kind described than can be attributed to any other one

cause. For this reason the contraction joints should be given very careful attention at the time of construction.

It has been claimed that the difficulty involved in properly maintaining defects in joints and cracks and the inconvenience attending periodic renewals of the pavement may be largely eliminated by maintaining a bituminous wearing surface over the concrete. Until further improvements are made in this method of treating concrete pavements, however, no specific recommendations can be made.

CONCLUSION.

In concluding this discussion of concrete roads the principal points may be summarized as follows:

(1) The economic efficiency of concrete roads is undetermined at present, but the indications are that this type of construction will prove to be well suited for certain conditions.

(2) The one-course type of concrete pavement is greatly to be preferred to the two-course type, but there are conditions under which the adoption of the two-course type of construction may be justified.

(3) The proportion of cement to the sand and coarse aggregate combined should not be less than about 1 to 5, and the proportion of sand to coarse aggregate should not be less than $1\frac{1}{2}$ to 3, nor greater than 2 to 3. Ordinarily, when gravel is used as coarse aggregate, the proportions may be made 1 part of cement to $1\frac{1}{2}$ parts of sand to 3 parts of gravel, and when crushed stone is used as coarse aggregate, 1 part of cement to $1\frac{3}{4}$ parts of sand to 3 parts of crushed stone.

(4) All types of contraction joints which have yet been devised require careful and frequent attention in order to prevent rapid deterioration of the pavement in their vicinity. It appears that better results are obtained by spacing the joints at an angle of about 75° to the center line of the road than when they are placed at an angle of 90°.

(5) Thin bituminous wearing surfaces for concrete pavements can not be economically justified at present. It is possible that through experimental investigations some method of constructing such surfaces to give uniformly satisfactory results may yet be devised. If this is done, the maintenance of concrete pavements and the contraction-joint problem will be greatly simplified.

(6) Intelligent engineering supervision is absolutely essential in concrete pavement construction, because defective materials or workmanship can not be readily repaired after the pavement is completed, and they are not usually apparent until the pavement has been in use for some time.

(7) It is believed that the following specifications typify the best practice which has been developed in concrete pavement construction.

It should be borne in mind, however, that some of the requirements which they contain are necessarily tentative and will probably be modified as experience demonstrates what methods of construction produce the best results.

APPENDIX.

Typical Specifications for Grading, Building all Necessary Drainage Structures, and Surfacing With Concrete the ——— Road.

LOCATION.

The work referred to in these specifications is to be done on the ______ road, beginning at ______ and extending in a ______ direction through ______ to ______, a distance of ______ miles.

WORK TO BE DONE.

The contractor shall do all clearing and grubbing, make all excavations and embankments, do all shaping and surfacing, construct all drainage structures and other appertaining structures, move all obstructions in the line of the work, and, unless otherwise provided in these specifications, shall furnish all equipment, materials, and labor for the same. In short, the contractor shall build said road in strict accordance with the plans and specifications and shall leave the work in neat and finished condition.

PLANS AND DRAWINGS.

The plans, profiles, cross sections, and drawings on file in the office of ______ at ______ show the location, profile, details, and dimensions of the work which is to be done, and shall be considered as a part of these specifications. The work shall be constructed according to the above-mentioned plans, profiles, cross sections, and drawings. Any variation therefrom, as may be required by the exigencies of construction, will in all cases be determined by the engineer. On all drawings figured dimensions are to govern in cases of discrepancies between scale and figures.

GRADING.

Grading shall include all excavating, filling, borrowing, trimming, picking down, shaping, sloping, and all other work that may be necessary in bringing the road to the required grade, alignment, and cross section; the clearing out of waterways and old culverts; the excavation of all necessary drainage and outlet ditches; the grading of a proper connection with all intersecting highways; the grubbing up and clearing away of all trees, stumps, and boulders within the lines of the improvement, and the removal of any muck, soft clay, or spongy material which will not compact under the roller so as to make a firm unyielding subgrade.

All trees, stumps, and roots within the limits of the improvement shall be grubbed up so that no part of them shall be within six (6) inches of the surface of the ground or within eighteen (18) inches of the surface of the subgrade, except that, if they occur in an area to be covered by a fill more than eighteen (18) inches in depth, they shall be grubbed up or cut off even with the present surface of the ground.

Embankments shall be formed of good sound earth or stone and carried up full width. The material shall be deposited in layers not more than one (1) foot in thickness and each layer shall be rolled until thoroughly compacted

with a roller weighing not less than ten (10) tons. All existing slopes and surfaces of embankments shall be plowed or scarified where additional fill is to be made, in order that the old and new material may bond together. When sufficient material is not available within the fence lines to complete the embankments, suitable borrow pits from which the contractor must obtain the necessary material will be designated by the engineer. If there is more material taken from the cuts than is required to construct the embankments, as shown on the plans, the excess material shall be used in uniformly widening the embankments or shall be deposited where the engineer may direct. Where embankments are formed of stone, the material shall be carefully placed so that all large stones shall be well distributed and the interstices shall be completely filled with smaller stone, earth, sand, or gravel, so as to form a solid embankment.

During the work of grading, the sides of the road shall be kept lower than the center and the surface maintained in condition for adequate drainage.

The grading of any portion of the road shall be complete before any surfacing material is placed on that portion, and where the plans do not call for any substantial change in the grade of any existing section of the road, the surface shall be completely scarified to a depth of three (3) inches or more before the subgrade is prepared.

All excavated material[1] will be classed as earth and rock. Only rock in place which requires blasting for its removal and boulders of one-half cubic yard or more in volume will be classed as rock excavation.

Materials obtained from excavation and used in embankments will be paid for as excavation only, though the contractor is required to shape and trim the embankments properly. Materials obtained from excavation and used for surfacing will be paid for only once and at the price bid for surfacing material.

Quantities of materials moved in grading will be measured in excavation and the volumes determined by the average end area method, and no payment will be made for materials excavated outside the slope lines shown on the plans unless the additional excavation is ordered by the engineer.

The contract prices for excavation shall be compensation in full for all the work which is required to be done under the heading "grading," except that an additional allowance at the rate of one and one-half ($1\frac{1}{2}$) cents per cubic yard per one hundred (100) feet will be made for all materials of excavation necessarily hauled more than five hundred (500) feet. The centers of gravities of cuts and corresponding embankments will be used in determining the length of haul, and if the center of gravity of the cut is more than five hundred (500) feet from the center of gravity of the corresponding fill, overhaul will be allowed for the entire amount of material in the cut for the actual distance in excess of five hundred (500) feet.

DRAINAGE STRUCTURES.

[Insert technical specifications for necessary drainage structures.]

SUBGRADE.

The subgrade, or that portion of the road upon which the concrete surface is to be laid, shall consist of good sound earth brought to the proper elevation,

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[1] In general, it is more satisfactory to classify the materials of excavation and to invite unit-price bids rather than lump-sum bids. However, if unit-price bids are invited, it is important that the various quantities be accurately determined in order that the best bid may be selected. If lump-sum bids are desired, omit the following paragraphs.

alignment, and cross section, and shall be rolled until firm and hard with a roller of the macadam type weighing not less than ten (10) tons and not more than fifteen (15) tons. Should earth be encountered which will not compact by rolling so as to be firm and hard, it shall be removed and replaced with suitable material, and that portion of the subgrade shall be again rolled. When the rolling is completed, the surface of the subgrade shall conform to the cross section shown on the plans and shall have the proper elevation and alignment, and shall be so maintained until the concrete surface is in place.

SHOULDERS.

The shoulders shall be partially built up at the time the subgrade is being prepared, and before the pavement is opened to general traffic they shall be carefully graded to the required cross section and shall be thoroughly compacted by rolling with a roller weighing not less than ten (10) tons and not more than fifteen (15) tons.

The contract price for shaping subgrade and shoulders shall be compensation in full for all work required of the contractor under the headings "Subgrade" and "Shoulders."

MATERIALS.

Cement.—The cement for use in this work shall meet the requirements of the United States Government specification for Portland cement, as published in Circular No. 33, United States Bureau of Standards, issued May 1, 1912.

All cement shall be held at least ten (10) days after sampling, before it is used in any part of the work. If the cement satisfactorily passes all tests that may be made within that time, it may be used, and the 28-day test will not be insisted upon, but if it should fail to pass satisfactorily any test made within that time, then the cement shall not be used until it has passed satisfactorily all tests, including the 28-day test. All cement shall be delivered on the work in cloth or paper bags containing ninety-four (94) pounds net weight, and this amount of cement shall be considered as having a volume of one (1) cubic foot. In order to allow ample time for inspecting and testing, the cement shall be stored in a suitable weather-tight building having the floor blocked or raised from the ground, and shall be stored so as to permit of easy access for proper inspection and so that each carload shipment may be readily identified.

Sand.—The sand for use in the concrete shall be composed of particles of hard, durable stone, and not more than three (3) per cent, by weight, of clay, loam, or silt. No clay, however, will be permitted if it occurs as a coating on the sand grains. The grains shall be of such sizes that all will pass a one-fourth (¼) inch mesh screen; that not more than twenty (20) per cent will pass a No. 50 sieve; and that not more than sixty (60) per cent nor less than twenty (20) per cent will be retained on a No. 20 sieve. The sand shall be of such quality that a mortar made in the proportion of one (1) part of cement to three (3) parts of the sand, according to standard methods, when tested at any age not exceeding twenty-eight (28) days, will have a tensile strength of at least one hundred (100) per cent of that developed in mortar of the same proportions made of the same cement and standard Ottawa sand. The cement used in these tests shall be from an accepted shipment of that proposed for use with the sand.

Gravel.—The gravel for use in the concrete shall be composed of hard, sound, durable particles of stone, and not more than one (1) per cent, by weight, of clay, loam, or silt. No clay, however, will be permitted if it occurs as a

coating on the particles of stone. The particles of stone shall be graded in size between those retained on a screen having circular openings three-eighths (⅜) inch in diameter (or a one-fourth (¼) inch mesh screen) and those passing a screen having circular openings one and one-half (1½) inches in diameter. Not less than twenty (20) per cent shall be retained on and not less than twenty (20) per cent shall pass a screen having circular openings three-fourths (¾) inch in diameter. The gravel shall be free from particles of soft sandstone, shale, slate, coal, or other material which may readily disintegrate.

Crushed stone.—Crushed stone for use in the concrete shall be composed of particles of clean, sound, durable stone, crushed to such sizes that all will be retained on a screen having circular openings three-eighths (⅜) inch in diameter (or a one-fourth (¼) inch mesh screen) and will pass a screen having circular openings one and one-half (1½) inches in diameter. Not less than twenty-five (25) per cent shall be retained on and not less than twenty-five (25) per cent shall pass a screen having circular openings three-fourths (¾) inch in diameter.

Samples of the stone when subjected to the hardness, toughness, and abrasion tests, as described in United States Office of Public Roads Bulletin No. 44, shall satisfactorily meet the following requirements:

Hardness, not less than ten (10); toughness, not less than eight (8); and per cent of wear, not more than four (4).[1]

Water.—The water used in mixing the concrete shall be free from oil, acid, alkali, and vegetable matter, and fairly free from clay or silt.

CONSTRUCTION.

Mixing and placing concrete.—Upon the subgrade, prepared as herein specified, shall be laid a concrete surface of the width, thickness, and cross section shown on the plans. The subgrade shall be wet but not muddy when the concrete is placed upon it. The concrete shall be composed of the following materials proportioned by volume: One (1) part of cement, one and one-half (1½) parts of sand, three (3) parts of gravel, and sufficient water to form a quaky mass; or one (1) part of cement, one and three-quarters (1¾) parts of sand, three (3) parts of crushed stone, and sufficient water to form a quaky mass. The materials shall be thoroughly mixed in a machine mixer of the batch type, so designed, constructed, and operated that the thorough mixing of the materials is assured and that the consistency of all batches is the same. The operations of transporting the concrete from the mixer to its proper place in the road and of spreading and tamping it in place shall be so conducted as not to cause or permit any separation of the materials of the concrete. The concrete shall be placed between the forms, hereinafter described, and the surface shall then be shaped, true to grade and to a cross section having one-fourth (¼) inch more crown than that shown on the cross-section drawings by means of a well-constructed "strike board." When the concrete is thus shaped, it shall be tamped until mortar flushes to the surface in such quantity as to fill completely all the voids between the particles of the coarse aggregate. The tamping shall be done with a template having a face not less than six (6) inches in width and conforming with the crown shown on the cross-section drawings, or by some other device equally as satisfactory to the engineer. When the tamp-

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[1] Stone of only fair quality will meet the above requirements for hardness, toughness, and per cent of wear, and if better stone is available these requirements should be such as to insure its use. It is also desirable to list the available varieties of stone which would be acceptable.

ing is completed, the surface of the concrete shall be finished by floating it with wooden floats. The finished surface shall be free from porous or open spots. No portion of it shall be more than one-half (½) inch below a template, cut to the crown shown on the cross-section drawings, placed on the pavement at right angles to the center line of the road, and no portion of it shall be more than one-half (½) inch below a straightedge ten (10) feet in length or more than one-fourth (¼) inch below a straightedge three (3) feet in length, laid on the pavement parallel to the center line of the road.

Protection.—After the concrete surface has been finished, as above described, it shall be entirely covered with canvas as soon as this can be done without marring its surface. The canvas shall be kept wet until the concrete has set to such an extent that the surface of the pavement will not be marred by men walking upon it (about twenty-four (24) hours), and it shall then be removed. Immediately after the canvas has been removed, the surface of the concrete shall be covered with a two (2) inch layer of earth, which shall be thoroughly wet with water immediately after it is placed upon the concrete, and shall remain in place and be kept wet with water for at least two (2) weeks. It shall be removed before traffic is permitted upon the concrete surface. During this period of two weeks or longer, as the engineer may require, on account of weather conditions, no traffic whatever shall be allowed upon the concrete.

Forms.—The forms shall be smooth, clean, free from warp, of sufficient strength to resist springing out of shape, of a width equal to the edge thickness of the pavement, and so designed that the various sections may be fastened together in such a manner as to prevent relative vertical movement of the ends. The forms shall be set true to line and grade, shall be well staked and braced, and shall have a firm bearing.

Joints.—Joints shall be spaced thirty (30) feet apart where gravel is used as coarse aggregate and fifty (50) feet apart where crushed stone is used as coarse aggregate. They shall be perpendicular to the subgrade, extend entirely through the concrete pavement, and be located at an angle of seventy-five (75) degrees with the center line of the road. The joint shall be one-fourth (¼) inch in width, and the abutting ends of the concrete sections shall be separated by asphaltic or tar felt one-fourth (¼) inch in thickness extending the full width and depth of the pavement. The surface of the concrete pavement on each side of the joint shall be true to grade and cross section.

The contract price for the concrete pavement shall be compensation in full for furnishing all materials, laying, sprinkling, and protecting the concrete, furnishing and setting all forms, constructing necessary contraction joints, and doing all other incidental work.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 250

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C. PROFESSIONAL PAPER July 24, 1915.

FOOD PLANTS OF THE GIPSY MOTH IN AMERICA.

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CONTENTS.

SCOPE OF THE INVESTIGATION.

Since the time the gipsy moth (*Porthetria dispar* L.) became abundant enough in Massachusetts to require treatment in order to prevent the defoliation of trees and shrubs the question of its favored food plants has been under consideration.

During the period from 1890 to 1900 an attempt was made by the State of Massachusetts to exterminate this insect, and a study of the different species of plants upon which the caterpillars would feed was made prior to 1896 and published that year by Forbush and Fernald in their report on the gipsy moth. These experiments were carried on with nearly full-grown caterpillars, a small number being confined in a jar with each food plant. If no feeding was noted in three days the experiment was repeated with other caterpillars, and if the same result was secured for this lot the food plant was considered unfavored by the caterpillars. As a result of these experiments 477 species of trees, shrubs, and plants were tested, and 458 of these were

Note.—This bulletin reports a series of investigations conducted in 1912, 1913, and 1914 to determine the favored food plants of the gipsy moth. The subject is of interest to entomologists and to State authorities engaged in the fight against the gipsy moth in the northeastern States.

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eaten to a greater or less extent. On 27 species the larvæ fed very slightly, and on 19 no feeding was noted.

In 1905, when work to control the gipsy moth was resumed, after a lapse of five years, it was found that the infestation had spread over such a wide territory that extermination of the moth was impossible. The following year (1906) an appropriation was made by Congress and control work to prevent the spread of this insect was commenced by the Bureau of Entomology. The infestation was so heavy in eastern Massachusetts that the principal efforts, aside from parasite introduction, was to clear the main highways in order to prevent the distribution of caterpillars through the medium of passing vehicles. As early as 1907 it was noticed by a number of observers that some species of trees were more often defoliated than others. These observations also indicated that pine was one of the species which was not readily attacked. In order to secure more information on this subject a number of experiments were carried on by the writer under the direction of Mr. A. H. Kirkland, who was superintendent of moth work for the State of Massachusetts.

The preliminary work was commenced in the spring of 1907, newly hatched caterpillars of the gipsy moth being placed in jars and furnished with pine foliage. In the feeding experiments it was not possible to induce newly hatched caterpillars to feed and develop on white pine, but when they were furnished with oak foliage no serious difficulty was encountered. Several field experiments were also carried on to determine whether a pine growth could be protected from the gipsy moth by placing bands of tanglefoot on the trees in order to prevent caterpillars from climbing to the foliage. These experiments were repeated the following season, and on account of the success of the field experiment, wherein several acres of pine growth were protected by using tanglefoot bands, it was obvious that more detailed information regarding food plants was necessary to the proper conduct of the work than had been secured from the experiments reported in 1896. Numerous field observations and several experiments of greater scope were then conducted, but in 1911 it seemed desirable to investigate, in a thorough and systematic way, the entire matter of preferred food plants. Accordingly plans were formulated to carry on an elaborate series of laboratory experiments, using first the more common trees occurring in the infested ments at the Gipsy Moth Laboratory of the Bureau of Entomology at Melrose Highlands, Mass., using first the more common trees occurring in the infested region, with the idea of taking up the rarer species, as well as the woodland shrubs and undergrowth, as soon as opportunity permitted. The experiments were arranged so that two lots of

caterpillars were fed upon the foliage of two trees of the same species, and care was taken that the foliage for each lot was always secured from the same tree. The experiments were begun by using 100 caterpillars that had just hatched for each lot, the plan being to carry on the feeding tests during each of the 6 caterpillar stages (Pl. I, fig. 1) in order to determine any variation in feeding habits in the different larval stages. In conducting these experiments special feeding trays were constructed, and the many details in the keeping of notes and records, the collection of foliage, etc., were worked out. To supplement these experiments and to give data which would furnish a check on the results secured, observations were made throughout the infested region during the summer of 1912 on the feeding habits of gipsy-moth larvæ in the field.

In 1912 the infested territory was divided into 5 sections for the purpose of determining the natural increase of the gipsy moth under varying field conditions. This work has been supervised by Mr. C. W. Minott, and the sections have been in charge of Messrs. H. R. Gooch, I. L. Bailey, E. A. Proctor, J. V. Schaffner, jr., and W. A. Shinkwin. As a part of the summer work each of these men, with one assistant, has secured notes and information on the feeding habits of the gipsy-moth larvæ. The food-plant work has now been carried on both in the field and at the laboratory at Melrose Highlands, Mass., for three consecutive years—1912, 1913, and 1914.

During the summer of 1912 and 1913 a small sublaboratory was maintained at Worcester, Mass., through the courtesy of the board of park commissioners of the city of Worcester. The experiments were in charge of Mr. C. W. Collins in 1912 and of Mr. R. Wooldridge in 1913.

The object of the work at this laboratory was to determine whether the same results would be secured from foliage gathered in an area where the gipsy moth had never become abundant and defoliation had not existed, as compared with foliage taken from the somewhat debilitated tree growth in eastern Massachusetts, where many of the trees had been defoliated one or more times. The results secured indicated that no marked difference could be noted from foliage secured from these two regions, hence the sublaboratory was discontinued at the end of the second season.

The experimental work on food plants of the gipsy moth has now reached a stage from which reasonably conclusive results may be secured. The information is of special value since it forms a working basis for reforestation in the infested areas and is of value in suggesting the tree species which will be more immune from gipsy-moth attack.

EQUIPMENT OF THE LABORATORY.

In early spring a part of the experiments were started in the laboratory, but the trays were soon transferred to a large outdoor insectary. It was found necessary to use canvas curtains on the sides of the insectary in order to shade the trays in fair weather and to prevent the entrance of excessive moisture and wind during storms.

The rearing trays used were of two sizes, depending on the age of the caterpillars. For the small larvæ the trays measured $6\frac{1}{4}$ by $6\frac{3}{4}$ by 2 inches, and trays $12\frac{1}{4}$ by $12\frac{1}{4}$ by $2\frac{1}{2}$ inches (all inside measure) (Pl. I, fig. 2) were used for the larger caterpillars. These trays were of seven-eighths-inch dressed pine, having a narrow band of tanglefoot applied on the inside of the frame near the top. A piece of cotton cloth was pasted to the bottom of the tray, and two clamps were attached to the inside to hold in place a small bottle, three-fourths inch square and 4 inches long, provided with a crooked neck. The bottle was filled with water and a cork was inserted, through which was placed the end of a sprig of foliage, after which the bottle was secured in the tray by the clamp. It having developed that young larvæ exhausted themselves greatly by trying to crawl around on the cloth bottom of the tray, this covering was abandoned after the first summer's experience and a tray made of paraffined paper (Pl. II), of the proper size to fit into the wooden frames, was substituted. To replace the two brass clamps a single elbow screw was used, which held the bottle firmly but allowed it to be quickly removed.

METHODS OF CONDUCTING LABORATORY EXPERIMENTS.

Early in the spring, trees or shrubs to be used for a food supply were selected and properly tagged. Careful notes were kept of the condition of each, as well as the degree of gipsy-moth infestation upon them and upon the surrounding growth at the time the selection was made. As soon as hatching began feeding trays were given the same serial numbers as the trees or shrubs that had been previously tagged, the foliage from the same plant always being used in the same tray. One hundred newly hatched gipsy-moth caterpillars were placed on the foliage in each tray. The food was replenished daily or oftener if necessary, and a careful record of the number of caterpillars that died or molted was maintained. In cases where all the caterpillars died before pupation, new trays were started, using caterpillars one stage younger than those in the tray at the time it was discontinued.

About 60 species of trees and shrubs were tested annually at the Melrose Highlands Laboratory; and as a number of retests and special experiments were conducted each year, 150 trays were in use continu-

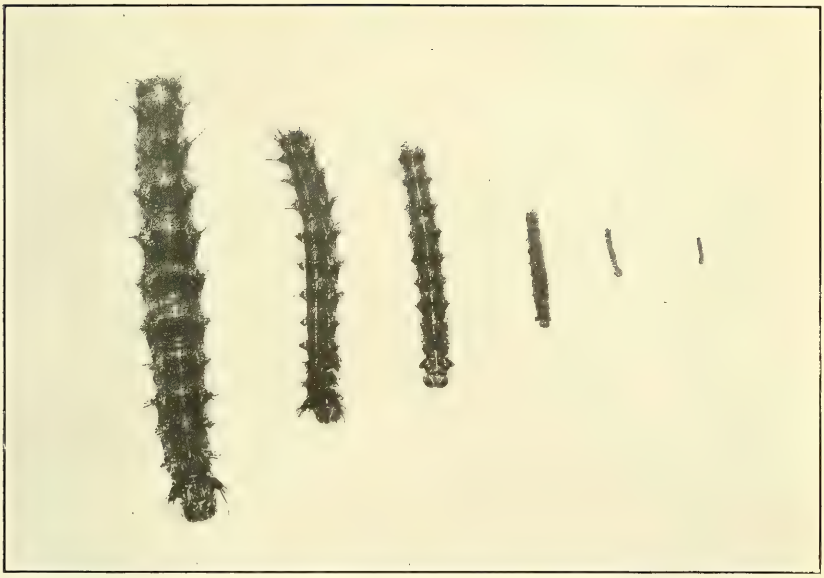
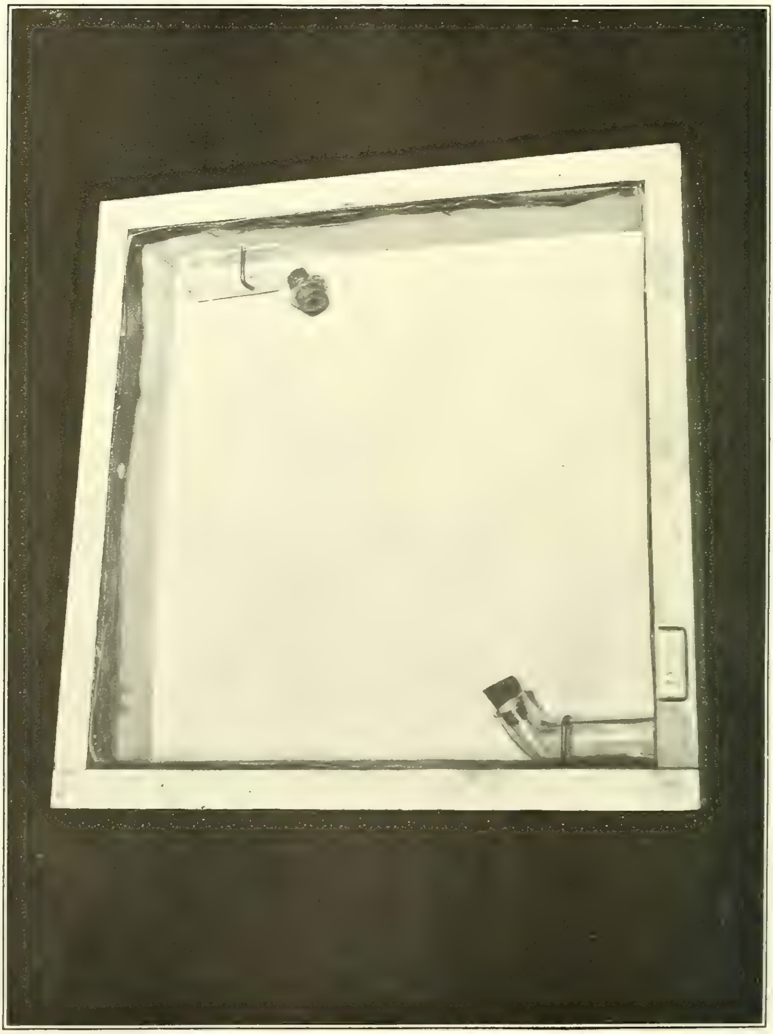


FIG. 1.—GIPSY-MOTH LARVÆ IN FIRST TO FIFTH STAGES. NATURAL SIZE. (ORIGINAL.)

FIG. 2.—TRAY USED FOR FEEDING GIPSY-MOTH CATERPILLARS.

Note that this tray has a cloth bottom, a band of tanglefoot near the top, and is supplied with a bottle of water into which the sprig of foliage is inserted. (Original.)

GIPSY-MOTH LARVÆ AND IMPROVED FEEDING TRAY.



IMPROVED TRAY USED FOR FEEDING GIPSY-MOTH CATERPILLARS.

Note that the bottom and sides are made of one piece of heavy paper which has been treated with paraffin. (Original.)

ously throughout the feeding season. It required the services of five assistants to attend properly to the feeding work and to record the necessary data. In addition, two assistants were employed to collect the food plants that were used in these experiments. Some of the species could not be secured in Melrose, and in a number of cases considerable travel was necessary in order to supply the foliage for the tests. During the summer of 1914 an assistant provided with a motorcycle was able to collect most of the foliage.

About the same number of assistants was required to conduct the experiments at the sublaboratory at Worcester, Mass., during the summers of 1912 and 1913.

A few tests or field observations were made on European trees and shrubs which occur in New England, but no effort has been made in this report to consider the food plants of the gipsy moth in Europe.

DIFFICULTIES IN CONDUCTING THE EXPERIMENTS.

As a result of previous experience in feeding caterpillars, it seemed necessary to secure a better method than simply placing leaves or twigs with foliage in the trays. When this is done the leaves wither rapidly in warm weather and often become so dry that it is extremely difficult to find all the first-stage caterpillars when the trays are cleaned. The use of the bottles of water in the trays obviated this trouble to a great extent and made the cleaning of the trays relatively easy. There were several kinds of foliage, such as linden, sassafras, and young growth of hickory, walnut, etc., that wilted rapidly in spite of every precaution that was taken.

In most of the trays a considerable number of caterpillars died from the disease known as "wilt," and in a few cases the imported parasites produced heavy mortality among the gipsy-moth larvæ. These factors operated in varying degrees during different seasons, but had an important bearing on the number of larvæ that survived the tests.

FOOD PLANTS TESTED.[1]

NOTE.—The writer expresses his appreciation to all who have assisted in these experiments. Special thanks are due to the Board of Park Commissioners of Worcester for the use of the sublaboratory in their city and to Mr. A. V. Parker, superintendent of parks, and Mr. H. L. Neale, city forester, for many courtesies extended; to Dr. C. S. Sargent and his assistants for permission to secure foliage at the Arnold Arboretum for some of the experiments; and to Mr. H. A. Preston for preparing the photographs illustrating this report, as well as to the many other employees of the Gipsy Moth Laboratory who have contributed toward the data summarized in this report.

[1] The botanical designations, both scientific and common names, herein cited are verified by Britton and Brown, Illustrated Flora of the Northern States and Canada. Second Edition, Vols. I–III, New York, 1913.

In the following pages are given a brief statement of the results secured with each food plant tested. Field observations are also included to make the data as reliable as possible. Experience has shown that results, even with the same food plant, vary to some extent during different years; and as the information is based upon three years' work, it is believed that this variability has been given due consideration.

It should be remembered that in the trays the larvæ were furnished with the same species of foliage during the entire season, hence the results are not exactly the same as would be secured under field conditions where a variety of food is usually available. A certain amount of injury to caterpillars always results from handling them in trays, so that the rate of reproduction in the experiments is in all cases less than under field conditions.

ALDER, SPRECKLED (*Alnus incana* [L.] Willd.).

In the tray experiments the larvæ fed freely in all stages. The growth and reproduction were normal. The field observers agree that gipsy-moth larvæ usually feed in all stages on this plant, but in the first three stages it seems to be preferred. As alder is of little commercial value it should be removed when cuttings are being made. (Pl. III, fig. 2.)

APPLE (*Pyrus malus* L.).

This species was found to be a favorite food of gipsy-moth larvæ both in the field and in the trays. In combination with other growth it is usually the most heavily infested.

Old trees of this species that have been neglected nearly always contain holes and crevices in which the gipsy-moth larvæ hide and go through their transformations, the females depositing their eggs where it is difficult to find them. These trees are a menace to the surrounding growth and should be removed.

ARBOR VITÆ (*Thuja occidentalis* L.).

No observations were made on this species in the field, but it has been thoroughly tested in the laboratory. No reproduction was secured until experiments were carried on with third-stage larvæ. The feeding was slight and development was slow and imperfect. It is an unfavored food.

This species can be left in a stand of trees without fear of injury by the gipsy moth.

BLACK ASH (*Fraxinus nigra* [Marsh.]).

One adult male was reared from 100 larvæ started in the third stage. Many other tests were less favorable to the insect. Mr. T. J. Kennedy, one of the field observers, reports no feeding on this species of ash in southern New Hampshire. It is an unfavored species.

BLUE ASH (*Fraxinus quadrangulata* Michx.).

A single specimen of this tree was under observation. It was located in Elm Park, Worcester, and foliage was tested in the trays in the Worcester laboratory by Mr. Collins in 1912.

Although larvæ from the first to the fifth stages, inclusive, were tried, none reached the adult stage. It is an unfavored species.

MOUNTAIN ASH (*Pyrus americana* [Marsh.] D.C.).

No observations were made on this species by the field men.

Tray experiments for a single season at Worcester were not conclusive, but the results at Melrose Highlands indicated that larvæ will feed continuously on this plant from the first stage and reproduce normally.

RED ASH (*Fraxinus pennsylvanica* Marsh.).

But few field observations were obtained on this species, and those were to the effect that gipsy-moth larvæ do not feed on red ash.

All larval stages from the first to the fourth, inclusive, were tested at the Melrose Highlands laboratory, but no pupæ were obtained.

When the blossoms were placed with the foliage in the trays, there was considerable feeding on the former but the leaves were not injured.

WHITE ASH (*Fraxinus americana* L.).

This most common species of Fraxinus has been noted by all the field observers, but none reported feeding on the foliage by gipsy-moth larvæ except where other species of trees are nearly or wholly defoliated. Even then there was little feeding in most cases. Mr. Proctor reports that branches on several trees of this species were completely stripped in an area badly defoliated by the gipsy moth.

White ash was tested in 1912 both at Worcester and Melrose Highlands. At the former laboratory, the larvæ from the first to the fifth stages, inclusive, produced no pupæ. At Melrose Highlands trays started with fourth-stage larvæ produced male moths only.

FLAME AZALEA (*Azalea lutea* L.) AND WHITE AZALEA (*Azalea viscosa* L.).

Mr. Schaffner had the former species under observation and found that wherever it was situated in badly infested localities feeding on the foliage was rather heavy. This foliage will probably sustain the gipsy-moth larvæ in all stages, but the tray work at Melrose Highlands failed to bring them through from either the first or second stages. From two trays started with third-stage larvæ, male moths were secured.

There was practically no difference in the amount of feeding on these two species.

EUROPEAN BARBERRY (*Berberis vulgaris* L.).

Barberry has been under observation in the field, and all the observers have found gipsy-moth larvæ in all stages feeding upon it. It is not considered a particularly favored food, as larvæ feeding upon it seemed quite susceptible to disease.

The species will support the larvæ in all stages, adults having been reared from trays started with first-stage caterpillars.

BAYBERRY (*Myrica carolinensis* Mill.).

In sparsely infested territory, feeding on this species is light, but when the infestation is heavy these shrubs are sometimes completely defoliated.

Reproduction has been satisfactory when small caterpillars have been tested in the trays.

American Beech (*Fagus grandifolia* Ehrh.).

Field observers all agree that gipsy-moth larvæ feed heavily on this species during the first three stages, after which they migrate to other species and usually return to do considerable feeding during the last, or, in some cases, a part of the last two stages. Tray experiments verified this, for in the first three stages there was heavy feeding on the foliage, whereas in the fourth stage there was much less feeding and larval growth was retarded. These caterpillars were restless and appeared to be searching for different food. They died before reaching full growth.

It is evident that the beech must be associated in a mixture with one or more favored species in order that the gipsy moth may reproduce normally.

Black Birch (*Betula lenta* L.).

Field observations indicate that feeding on the black birch is somewhat variable, and it is seldom severely defoliated except in grossly infested areas.

The results secured from the tray experiments were also variable, and while it is possible for larvæ in all stages to survive on this foliage, they usually do not grow as rapidly or develop as vigorous individuals as when supplied with more favored food.

Apparently this tree comes near the line of favored and unfavored species.

Gray Birch (*Betula populifolia* Marsh.).

This species is more generally distributed than any other in the area infested by the gipsy moth.

All the observers agree that the larvæ feed on this birch through all stages and grow large and rapidly except, possibly, in the first stage. Reproduction of the moth on this tree is usually heavy.

In the laboratories the larvæ grew rapidly after the first stage and produced many moths.

One peculiarity was observed in the feeding of the larvæ; both at Worcester and Melrose Highlands the young larvæ fed almost wholly on the petioles of the leaves, severing them from the blades.

Several cases have been observed in the field where the bark on the tender twigs has been completely girdled by the larger larvæ.

This is one of the most favored food plants of the gipsy moth.

Paper Birch (*Betula papyrifera* Marsh.).

This birch is found quite plentifully in the higher altitudes of the gipsy-moth infestation, but in the low altitudes the species is represented by only a few widely scattered specimens.

In the field the larvæ feed on this tree in all stages, and total defoliation results if the infestation is sufficiently great. (Pl. III, fig. 1.)

In the tray work this species proved a very favored food. From one tray of first-stage larvæ at the Worcester laboratory, Mr. Wooldridge obtained 25 egg masses. Heavy reproduction was also obtained at the Melrose laboratory.

Red Birch (*Betula nigra* L.).

This species occurs in a few localities in New England. Mr. Proctor, who had trees under observation in the Merrimac Valley, reports feeding in all stages and defoliation toward the end of the season.

FIG. 1.—PAPER BIRCH FOLIAGE SHOWING PINHOLE FEEDING. (ORIGINAL.)

FIG. 2.—SPRECKLED ALDER FOLIAGE SHOWING SHOT-HOLE FEEDING. (ORIGINAL.)

TWO FOOD PLANTS OF THE GIPSY-MOTH LARVÆ.

WORK OF GIPSY-MOTH LARVÆ IN CRANBERRY.

a, Old growth at base, spring growth, buds, and blossoms near tip; *b*, vines showing where new growth has been cut off by gipsy-moth larvæ; *c*, new growth that has been cut off by gipsy-moth larvæ. Note that little feeding has taken place on the old growth. (Original.)

The tray experiments were not satisfactory because of the difficulty of securing a satisfactory food supply, but all the larvæ grew well in the early stages.

Red birch is a favored food plant.

Yellow Birch (*Betula lutea* Michx. f.).

Except in heavy infestations, most of the feeding on this species by gipsy-moth larvæ is done in the first three stages. The larvæ make small holes, extending entirely through the leaves, forming "pinholes," and a few days later "shot holes." If the infestation is bad and the associated species of food plants are defoliated, these birches are sometimes stripped.

In tray experiments male moths have been secured by feeding larvæ started in the first stage.

High Blackberry (*Rubus* sp.).

Field observations indicate considerable variation in feeding on this plant. Defoliation has seldom been reported, and then only when heavy infestations occurred. Under ordinary conditions the feeding on this species is very slight.

Low Blueberry (*Vaccinium vacillans* Kalm.).

Of the three species of Vaccinium under observation in this series of experiments, this is the most unfavorable. Larvæ in the field have been found feeding in all stages, but not to any extent, except in medium to grossly infested territory. Usually the last three stages do most of the feeding on these shrubs.

First-stage caterpillars fed in trays have produced moths, which indicated that the insect can survive on this species.

Tall Blueberry (*Vaccinium corymbosum* L.).

All the field observers consider *V. corymbosum* more susceptible to gipsy-moth attack than *V. vacillans*, but it is not favored when other food is available. When an infestation is fairly heavy it is not uncommon for these shrubs to be entirely denuded.

First-stage caterpillars have developed to the adult stage when fed in trays. The larvæ did not grow as rapidly as is normal and were undersize.

Blueberry (*Vaccinium angustifolium* Ait.).

The field observers pronounce this species the most susceptible to moth attack of our three common species. They note feeding in the early as well as the late stages, and the shrubs may be found in all stages of defoliation. When a tree has been completely defoliated by the larvæ and they migrate to another tree, these shrubs furnish food for the journey.

First-stage larvæ fed in trays grew rapidly and large vigorous adults resulted.

Box Elder (*Acer negundo* L.).

No field observations are recorded on this species.

Tray experiments indicate that this is one of the most susceptible of the maples to moth attack. The larvæ fed freely in all stages and grew to large size; specimens started in the first stage produced moths.

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GREENBRIER (*Smilax rotundifolia* L.).

No experiments were conducted on this species at the laboratory.

Observations in the field indicate that this species is seldom attacked.

SWEETBRIER (*Rosa rubiginosa* L.).

Mr. Schaffner found larvæ in the first four stages feeding to a slight extent on this foliage.

No tray experiments were conducted. It is an unfavored plant.

BUTTERNUT (*Juglans cinerea* L.).

In a single instance stripping of this species has been recorded. Mr. Proctor observed this at North Andover, Mass. Other reports indicate very light feeding.

In trays at Melrose Highlands and Worcester males were reared from 100 second-stage larvæ. The caterpillars fed very sparingly and grew slowly. This is an unfavored food plant.

HARDY CATALPA (*Catalpa speciosa* Warder).

No observations were made on this species in the field.

In the Melrose Highland laboratory the larvæ started in the first stage all died before molting. Each succeeding stage was tried, and a few lived long enough to molt once before dying. No adults were obtained. A very unfavored species.

RED CEDAR (*Juniperus virginiana* L.).

This tree is seldom eaten to any appreciable extent by gipsy-moth larvæ, and only in the worst infestations do they show the least feeding on the new growth. It is a common occurrence at the end of the larval season to find trees heavily infested, due to the larvæ having sought shelter from the hot July sun.

Trays were started with this cedar at the Melrose Highlands laboratory, using each succeeding stage of the larvæ from the first to the fifth, inclusive. No moths were produced as a result of feeding on this plant.

SOUTHERN WHITE CEDAR (*Chamæcyparis thyoides* [L.] B.S.P.).

Mr. Schaffner reports considerable feeding on these trees each year, and in 1913 it amounted to 75 per cent defoliation.

Tray records indicate that it is an unfavored species, although one male moth was obtained from 100 fourth-stage larvæ. It is probable that solid stands of this species will not be injured.

WINTERGREEN (*Gaultheria procumbens* L.).

Mr. Shinkwin notes feeding on the leaves of this plant by gipsy-moth larvæ, and in rare instances there was considerable eating of the fruit.

No tray experiments have been carried on with this species. It is unfavored food.

CHOKE CHERRY (*Padus nana* (Du Roi) Roemer).

This species is found as an undershrub in many wood lots. Very little feeding has been noted by any of the observers, and that was done almost wholly by the first three stages, the small larvæ making pinholes in the leaves.

In the trays, both at Melrose Highlands and Worcester, adults were reared. The larvæ thrived about the same as on wild red cherry and were of fair size. This species appears to be the most favored of the cherries.

Sweet Cherry (*Prunus avium* L.).

Trays started with newly hatched larvæ, both at the Worcester and Melrose Highlands laboratories, produced moths. The larvæ fed very slowly, especially in the later stages, and were of small size.

Mr. Shinkwin observed a single roadside tree in a badly infested area that was nearly defoliated by third and fourth stage larvæ.

Wild Black Cherry (*Prunus serotina* Ehrh.).

Adults were obtained from first-stage larvæ started in trays. These larvæ grew very slowly and were only about one-half normal size.

From all sections the observation is made that there is little feeding and by all stages. Mr. Shinkwin notes a case in a heavy infestation where wild black cherry was nearly defoliated.

Wild Red Cherry (*Padus virginiana* (L.) Mill.).

This cherry was fed upon very slightly by the gipsy-moth larvæ, usually in the first two stages and very slightly in the third. The blossoms were attacked more than the leaves.

In the trays at Melrose Highlands adults were secured from first-stage larvæ. They fed sparingly and grew very slowly.

Chestnut (*Castanea dentata* [Marsh.] Borkh.).

This species has been observed by all the field men, and they agree that gipsy-moth larvæ feed upon it to a limited extent in all stages except the first. If favored food plants are abundant, the larvæ soon confine their attention to these plants. Where the infestation is heavy and the favored food is consumed the chestnuts are sometimes stripped.

In the tray work at both laboratories no first-stage larvæ started on this foliage went through to the second stage. Second-stage larvæ fed and adults were secured.

Chokeberry (*Aronia melanocarpa* [Michx.] Britton).

First-stage larvæ fed freely on this species in the trays and produced adults. A small amount of feeding was noted in the field, mainly on the blossoms.

Cornus (*Cornus* sp.).

Mr. Proctor notes pinhole feeding on this species in the field, but the other observers do not record any feeding in the other sections.

In the trays none reached the adult stage, although tried with the different stages of the larvæ. It is an unfavored species.

Flowering Dogwood (*Cynoxylon floridum* [L.] Raf.).

This species was tried in the laboratory at Melrose Highlands with each successive stage of gipsy-moth larvæ and none reached the adult. More feeding was noted on the flowers than on the leaves. In the field, even in badly infested territory, only very slight feeding was noted. It is an unfavored species.

Red Osier (*Cornus stolonifera* Michx.).

In heavily infested territory some of the field observers have found slight feeding during the early part of the year. This did not extend beyond small holes in the leaves and notches in the edges.

In the laboratory each successive larval stage was tried on the foliage and no adults were obtained.

Cottonwood (*Populus deltoides* Marsh.).

Cottonwood is seldom found in this section, but was tried in the trays in order to know whether it is favored in case the moth spread to territory where this species is common.

About 10 per cent of the first-stage larvæ started on this foliage carried through to the second stage, when they all died. At least 10 per cent of the third-stage larvæ started in trays reached the fifth stage, but no adults were obtained. In the early stages the feeding was slight and growth accordingly slow, but in the later stages feeding was more free and growth more rapid.

No observations were made on this species in the field.

American Cranberry (*Oxycoccus macrocarpus* [Ait.] Pursh).

The larvæ eat but little of the foliage of the cranberry vines, but cut off the stems just above the old growth and also the stems of the flowers or newly set berries. (Pl. IV.) The habit of the larvæ is to feed at night and remain secreted during the day. By parting away the vines the larvæ may be found underneath, next to the cool earth, ready to come up when the sun goes down to continue the feeding. Bogs that appear to be entirely free of the pest may harbor great numbers that will greatly reduce the crop.

In the trays we failed to obtain adults from larvæ started in the first stage on this foliage. On the bogs, however, was evidence that larvæ hatched on the vines had come through to the adult stage without other food.

Red Currant (*Ribes vulgare* Lam.).

Tray experiments failed to produce any adults, although the different stages were fed upon the foliage. In the early stages there was more feeding according to size of larvæ than in the later stages, and the larvæ lived longer.

Mr. Schaffner noted very slight feeding on this species in the field. It is an unfavored food plant.

Bald Cypress (*Taxodium distichum* (L.) Rich.).

Bald cypress was tried with all larval stages in the trays and only a very small percentage went through to the next stage. None reached the adult stage. Feeding was very slight and there was practically no growth. It is an unfavored species.

Dangleberry (*Gaylussacia frondosa* (L.) T. & G.).

Larvæ in the third stage started on this foliage reached the sixth stage. No pupæ were obtained from any stage.

Mr. Schaffner made observations on this undershrub in the field and in one instance notes a defoliation of 50 per cent, but as a rule there is but slight feeding.

BUSH HONEYSUCKLE (*Diervilla diervilla* [L.] MacM.).

This is a very common shrub along roadsides and in waste places. Mr. H. W. Allen reports that it was not eaten in an infested area at Manchester, N. H. It is an unfavored species.

NARROW DOCK (*Rumex crispus* L.).

Mr. Bailey reports seeing first and second stage larvæ feeding on this dock in Pelham, N. H. But little feeding was noted, however. It is an unfavored species.

AMERICAN ELDER (*Sambucus canadensis* L.).

This foliage was used in trays for all stages of gypsy-moth larvæ up to and including the fourth stage, and but very few changed to the next stage. There was very slight feeding and no growth.

Several observers have seen larvæ on this species, but none note any feeding beyond a few pinholes or notches in edges of the leaves. It is an unfavored species.

AMERICAN ELM (*Ulmus americana* L.).

All stages of the larvæ were noted feeding on elm, but usually to a limited extent. In heavily infested areas, where other species are completely defoliated, the elm shows much feeding, but it does not appear to be a favorite food if other species are available. In the trays, adults were reared from larvæ started in the first stage on elm foliage. The growth, however, was slow and the feeding light.

The preference for this food seems to have changed in the last 20 years. In the early nineties the elms were considered favored food. In the spring and summer of 1894 elm was the food used in nearly all the experiments carried on in the Massachusetts State Laboratory, then located in Malden, Mass. The larvæ fed freely on it and grew rapidly. In the trays in 1912 it was apparently distasteful to them and they were constantly searching for other food.

ENGLISH ELM (*Ulmus campestris* L.).

Our only knowledge on this elm is from the tray experiments. The larvæ fed about the same on this species as on the native elm, but none reached the adult stage. A few reached the fifth stage that were started in the third stage. In the open they could probably develop from the egg to the adult.

SLIPPERY ELM (*Ulmus fulva* Michx.).

Tray experiments show this to be an unfavored food plant. Few larvæ passed to the next higher stage while being fed upon it.

Mr. Proctor notes slight feeding in the field in all stages where the infestation was heavy.

SWEET FERN (*Comptonia peregrina* [L.] Coulter).

Larvæ in all stages have been observed feeding on this shrub and in heavily infested localities defoliation has taken place. In spite of this evidence it is not a favored food, and if other species are present in considerable numbers the feeding is not usually heavy on sweet fern.

Tray experiments show slow feeding and very little growth. But few larvæ passed to the next higher stage.

Spice-bush (*Benzoin aestivale* [L.] Nees).

No field observations have been made on this rather common shrub.

In the trays the larvæ in all stages seemed to dislike the food and there was little or no growth. Death resulted in a short time from starvation and disease.

Balsam Fir (*Abies balsamea* [L.] Mill.).

Mr. Gooch has had this species under observation. On July 14, 1914, he found in a mixed growth which was nearly defoliated heavy feeding on this species by fifth and sixth stage larvæ. A few small trees were 75 per cent defoliated. No feeding was observed by earlier stages.

In the trays little feeding took place before the third stage, and then the larvæ began to die rapidly and no adults were reared. This is an unfavored species.

Sweet Gale (*Myrica gale* L.).

Foliage from this species used in two trays with newly hatched larvæ produced adult moths. This shows it to be a favored food plant, as the larvæ fed freely in all stages.

Mr. P. S. Coffin found fourth and fifth stage larvæ feeding freely on sweet gale in Candia, N. H. None of the other stages have been observed feeding upon it in the field.

Grape (*Vitis labrusca* L.).

Tray experiments with the foliage of wild grape with each stage of the larva shows that the latter will die before reaching the next stage. There was very little feeding, which consisted of small notches being made in the edges of the leaves.

Mr. Schaffner made observations on this plant in the field which agree with the results secured in the laboratory.

Hackberry (*Celtis occidentalis* L.).

Newly hatched larvæ started on this foliage reached the fifth stage before the last one died. They did not appear to care for the food and grew very slowly.

Mr. Schaffner watched one tree of this species, but found no feeding at any time upon it.

Pink Hardhack (*Spiræa tomentosa* L.).

All stages of the larvæ have been observed on this species in the field and slight feeding has been reported, but the foliage will not sustain life through the different transformations.

Larvæ in the trays died before reaching the succeeding stage.

White Hardhack (*Spiræa salicifolia* L.).

Tray experiments and field observations show that this species is unfavorable, since larvæ are unable to develop sufficiently to transform to the next stage.

Hawthorn (*Cratægus* sp.).

Field reports indicate that this species is freely eaten by the larvæ in all stages.

This species was tested in the Worcester laboratory and the larvæ fed freely in all stages, grew well and went through from first stage to adult. It is a favored food plant.

HAZELNUT (*Corylus americana* Walt.).

This is a favored food plant for all stages of the larvæ, although feeding is heavier during the first four stages.

In the laboratories the feeding in trays was general in all stages and male and female moths were reared from larvæ started in the first stage.

BEAKED HAZELNUT (*Corylus rostrata* Ait.).

Not as common as the above species. Field observations same as for *C. americana.*

Laboratory experiments had to be discontinued after the larvæ reached the third stage because the shrubs were sprayed with poison.

HEMLOCK (*Tsuga canadensis* [L.] Carr.)

This evergreen is capable of supporting life in all stages of the gipsy-moth larvæ. At the Worcester laboratory, Mr. Collins reared 2 males and 1 female from the two trays of first-stage caterpillars. At the Melrose Highlands laboratory no adults were reared.

The field observers note feeding in all stages on the foliage, but in the first stage it is the new growth only. The feeding increases in intensity with each successive stage. In the field few adults develop when this tree is the exclusive diet of the gipsy-moth larvæ. (Pl. V.)

BITTERNUT HICKORY (*Hicoria cordiformis* [Wang.] Britton).

No field observations were made on this hickory.

In the trays the larvæ fed quite freely in the first three stages, but the foliage appeared somewhat distasteful to them in all stages.

The tree will doubtless sustain the caterpillars through life, but is not a favored food plant.

MOCKERNUT HICKORY (*Hicoria alba* [L.] Britton).

This seems to be the most favored species of the hickories. Mr. Shinkwin reports nearly total defoliation of a few trees. Feeding is most noticeable in the early stages.

In the trays, first-stage larvæ were reared to the fifth stage only.

In heavy infestations, in a mixed growth, this tree may be severely defoliated.

PIGNUT HICKORY (*Hicoria glabra* [Mill.] Britton).

Pignut hickory has been watched by all the observers and slight feeding upon it has been noted in all stages. All are of the opinion that it is an unfavorable food plant. The first-stage larvæ begin feeding upon the bud scales and follow up by eating holes in the new unfolding leaves.

In the trays at Melrose Highlands started with first-stage larvæ, male moths were obtained. At no time was the feeding free, and growth was very slow.

SHAGBARK HICKORY (*Hicoria ovata* [Mill.] Britton).

Shagbark hickory is eaten by the gipsy-moth larvæ less than the other hickories. The field observers report considerable feeding on the bud scales and after these drop the feeding diminishes. All stages have been reported feeding upon it sparingly.

In the trays, both at Worcester and Melrose Highlands, larvæ started in the first stage died on or before reaching the third stage.

AMERICAN HORNBEAM (*Carpinus caroliniana* Walt.).

All larval stages feed upon this foliage, and defoliation results in badly infested territory.

This species was tried in both laboratories, and first-stage larvæ died on or before reaching the third stage.

HOP HORNBEAM (*Ostrya virginiana* [Mill.] Willd.).

In the tray experiments at Melrose Highlands and Worcester first-stage larvæ failed to develop beyond the third stage on this foliage.

Larvæ feed on this foliage in all stages in the field.

HIGHBUSH HUCKLEBERRY (*Gaylussacia baccata* [Wang.] Koch).

This is an unfavored food plant and will not sustain the larvæ until they are full grown. The observers report seeing the larvæ in all stages feeding upon this species; in most cases they were probably larvæ that had spun down from overhanging trees.

In the trays a few male moths were obtained from larvæ started in the second stage.

INKBERRY (*Ilex glabra* [L.] A. Gray).

In southeastern Massachusetts this species is common over large areas.

Tray experiments and field observations both show that the larvæ can not subsist upon it.

SMOOTH WINTERBERRY (*Ilex lævigata* [Pursh] A. Gray).

Larvæ have been reported on this species in all stages eating small holes or notches in the leaves. These were probably larvæ that had been shaken down from overhanging trees or had crawled from near-by species. None seemed to stay for extended feeding.

In the trays there was very slight feeding and no growth. The caterpillars died rapidly of starvation.

AMERICAN WHITE HOLLY (*Ilex opaca* Ait.).

Mr. Schaffner reports finding larvæ in the third, fourth, and fifth stages feeding slowly on this species.

Larvæ in the trays fed sparingly in the first stage, but died rapidly of starvation. In the succeeding stages there was hardly any feeding, and death resulted.

FEVERBUSH (*Ilex verticillata* [L.] A. Gray).

Tray experiments and field observations show that gipsy-moth larvæ will not subsist on this species. A few small notches in the leaves observed in the field and notches and small holes in the leaves in the trays constituted all the feeding. Larvæ died rapidly and did not grow at all.

LARGER BLUE-FLAG (*Iris versicolor* L.).

Mr. Kennedy found fourth and fifth stage larvæ feeding on this species in Hampton, N. H. The swamp was situated near a group of gray birches that were badly stripped; the larvæ were being blown off by the wind, and in searching for food crawled to these plants and partially defoliated them.

FIG. 1.—NORMAL HEMLOCK FOLIAGE, PHOTOGRAPHED JUNE 20, 1914.
(ORIGINAL.)

FIG. 2.—HEMLOCK TWIG PARTLY DEFOLIATED BY FOURTH-STAGE GIPSY-MOTH LARVÆ; PHOTOGRAPHED JUNE 20, 1914.

This tree was stripped of foliage before midsummer. (Original.)

WORK OF GIPSY-MOTH LARVÆ IN HEMLOCK.

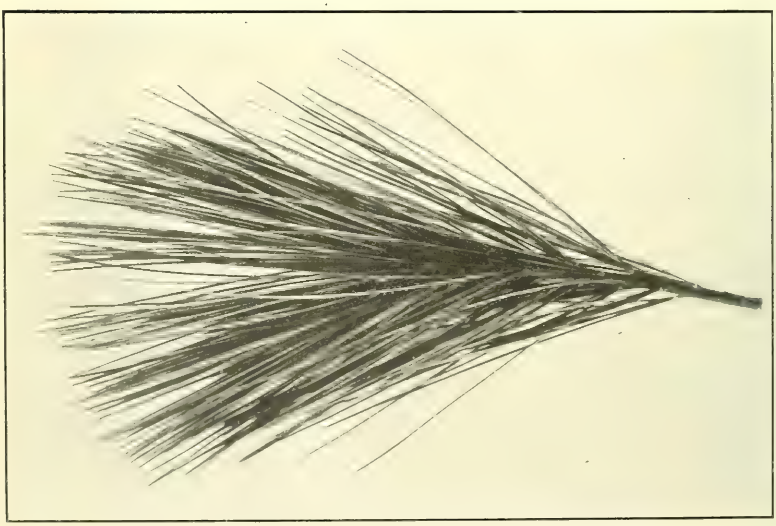

FIG. 1.—NORMAL WHITE-PINE FOLIAGE. (ORIGINAL.)

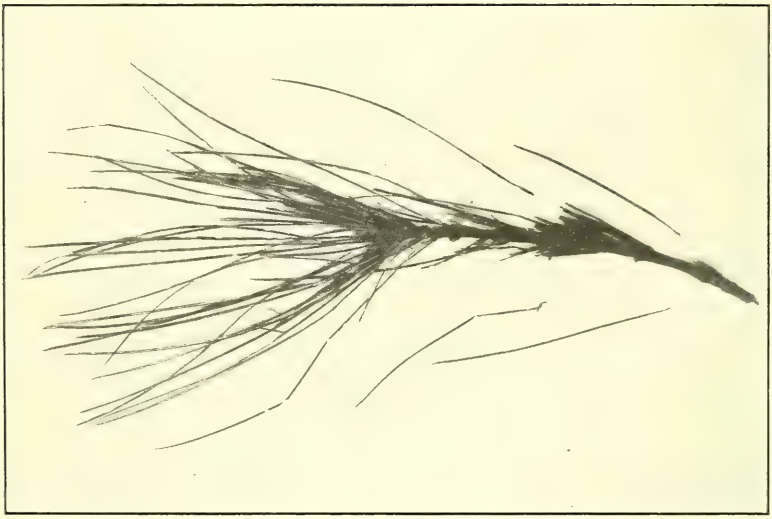

FIG. 2.—WHITE-PINE FOLIAGE BADLY INJURED BY GIPSY-MOTH LARVÆ.

Note the notches eaten in many of the needles.

WORK OF GIPSY-MOTH LARVÆ IN WHITE PINE.

POISON IVY (*Toxicodendron radicans* [L.] Kuntze).

Feeding by all stages except the sixth has been noted upon poison ivy. This resulted in a number of notches and small holes being made in the leaves. It is not a favorable food plant.

JUNIPER, COMMON (*Juniperus communis* L.).

Many of the field observers have seen feeding by gipsy-moth larvæ on this species in all stages, usually on the new growth.

Laboratory work shows that this species will not maintain this insect through the larval stage.

KENTUCKY COFFEE-TREE (*Gymnocladus dioica* [L.] Koch).

This species was tested at Worcester and also at the Melrose Highlands laboratories. In the first stage, before the bud scales dropped, there was considerable feeding. Later there was practically no feeding in any of the stages.

No field observations have been made on this species.

AMERICAN LARCH (*Larix laricina* [Du Roi] Koch).

Tray experiments show this to be a favored food for the gipsy-moth larvæ. They fed freely in all stages and grew rapidly and to large size. They were, however, badly attacked by disease, but adults were secured from experiments begun with first-stage caterpillars.

No field observations were made on this species.

EUROPEAN LARCH (*Larix decidua* Mill.).

Mr. Proctor notes feeding by first-stage larvæ on this species and in a diminishing degree in the second and third stages, after which no more feeding was noted. Observations were made in only one locality, and the species was not tested in the trays in the laboratory.

MOUNTAIN LAUREL (*Kalmia latifolia* L.).

Tray experiments show that this laurel will not support life of the gipsy-moth larvæ, as they would not feed upon it to any extent and die rapidly from starvation.

Two observers have seen slight feeding on this shrub by first, fourth, and fifth stage larvæ, the two latter stages working on the blossoms as well as the leaves.

SHEEP LAUREL (*Kalmia angustifolia* L.).

Field observations and tray experiments show that this species is distasteful to the caterpillars, as they eat only when no other food is available and then to a very limited extent. In the trays the larvæ died rapidly when furnished with no other food.

SWAMP EUBOTRYS (*Eubotrys racemosa* [L.] Nutt.).

Considerable feeding by all larval stages has been observed by Mr. Schaffner on this species in Middleboro.

In the trays it does not appear a very favorable food and no pupæ were obtained, as all larvæ died of disease and starvation.

American Linden (*Tilia americana* L.).

All field observers agree in calling this a favorable food for the gipsy-moth larvæ. It is eaten freely by all stages and is especially favored during the first three larval stages.

In the trays a fair percentage of adults were obtained from first-stage larvæ.

European Linden (*Tilia* sp.[1] L.).

Mr. Schaffner notes considerable feeding on this species by second and third stage larvæ.

In the trays this species did not seem to be as favored as the preceding one; the larvæ died rapidly and none pupated, although several reached the fifth stage.

Black Locust (*Robinia pseudoacacia* L.).

Slight feeding by all stages of the gipsy-moth larvæ has been observed in the field in mixed growth, where the infestation was bad.

In the trays the larvæ fed very sparingly and died rapidly. None before the third stage were carried to the adult stage, and all those reared were male moths. It is an unfavored species.

Honey Locust (*Gleditsia triacanthos* L.).

Results of the tray work show that this species ranks the same as the preceding.

No observations have been made in the field on honey locust.

Pepper-bush (*Xolisma ligustrina* [L.] Britton).

Slight feeding by gipsy-moth larvæ in all stages has been observed on this species in the field.

In the trays, feeding was very slow and little or no growth resulted. It is an unfavored species.

Mountain Maple (*Acer spicatum* Lam.).

No field observations have been made on this maple.

In the trays the first-stage larvæ fed freely, but after passing into the second stage feeding was much less, and none developed beyond the third stage. Very little feeding occurred in the later stages and no adults were obtained.

Norway Maple (*Acer platanoides* L.).

Adults, both male and female, were obtained from the trays started with first-stage larvæ on this foliage. The larvæ fed freely, especially in the later stages, and grew to good size.

No field observations were made on this maple.

Norway maple and the box elder are the most favored species of the maples. They are not as freely eaten, however, as many other food plants.

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[1] *T. platyphyllos* and *T. vulgaris* are the lindens usually included by nurserymen as *T. europæa*, hence the designation *Tilia* sp. is adopted in the absence of specific determination.

Red Maple (*Acer rubrum* L.).

When this maple is mixed with other trees more favored by gipsy-moth larvæ and the infestation is light, the feeding in all stages is light. When the infestation is heavy and the other trees in the combination become defoliated, or nearly so, the feeding becomes more intense, and in some cases defoliation of this maple results. It is not, however, a favored food and will usually be deserted for other species.

In the laboratory, adults were obtained from trays started with first-stage larvæ on this foliage.

Silver Maple (*Acer saccharinum* L.).

In trays, first-stage larvæ did not develop and produce adults, as all the former died in the fourth or earlier stages.

No field observations were made on this species. This is not as favored a food as red maple.

Striped Maple (*Acer pennsylvanicum* L.).

Larvæ started on this foliage in any stage failed to reach the next stage. It is one of the most unfavored of the maples.

No feeding of any amount was observed in the field.

Sugar Maple (*Acer saccharum* Marsh.).

Very few observations on this species have been made in the field, but the observers are agreed that it is an unfavored food.

In the trays at Worcester and Melrose Highlands the first-stage larvæ grew fairly well and a few male and female moths were obtained. It is less favored than Norway maple and about as susceptible to attack as the red maple.

Red Mulberry (*Morus rubra* L.).

Mr. Collins tested this species in the laboratory at Worcester and found it an unfavorable food for the gipsy-moth larvæ. A few specimens passed into the following stage, but none lived through two stages of it. No field observations have been made.

White Mulberry (*Morus alba* L.).

White mulberry was tested in the trays at Melrose Highlands and about the same results were obtained as with the red species, except that it is slightly more favorable than the former. One male was reared from a tray started with second-stage larvæ.

No field observations were made on this species.

Black Oak (*Quercus velutina* Lam.).

The oaks are among the most-favored food of the gipsy-moth larvæ. The young larvæ begin feeding as soon as the buds are about half open. This is a favored species and is eaten freely by all stages of the caterpillars and produces large and vigorous adults.

Rock Chestnut Oak (*Quercus prinus* L.).

This species is not common in the infested area, but wherever found the observers were unanimous in their reports that it is very favorable food.

The same conclusions were drawn from the tray experiments. The larvæ fed freely in all stages, growth was rapid, and they attained large size. A good percentage reached the adult stage.

Dwarf Chestnut Oak (*Quercus prinoides* Willd.).

No observations were made on this species in the field.

The larvæ fed freely in the laboratory during the first two stages. It then became necessary to discontinue the experiments, as the specimen trees were sprayed. It is undoubtedly a favored food plant.

Bur Oak (*Quercus macrocarpa* Michx.).

Larvæ fed freely on this foliage in all stages and grew rapidly, but all died of disease by the time they reached the sixth stage.

No field observations were made on this species.

Pin Oak (*Quercus palustris* Du Roi).

Larvæ fed on this foliage freely in all stages in the trays, especially in the first stage, but none reached the adult stage on account of disease.

No field observations were made on this oak.

Post Oak (*Quercus stellata* Wang.).

Trays started with newly hatched larvæ on this foliage produced adult moths. Larvæ fed freely in all stages.

No field observations were made on this species.

Red Oak (*Quercus rubra* L.).

This is one of the most abundant oaks and the records of field observations are voluminous. All are agreed that the larvæ feed ravenously on it in all stages and that large vigorous larvæ are produced. This is usually one of the first species to be entirely defoliated in a mixed growth.

In the trays the larvæ fed freely in all stages and good reproduction resulted.

Scarlet Oak (*Quercus coccinea* Wang.).

In most of the infested territory this oak is found to some extent and all are agreed that it is eaten by larvæ in all stages, but usually not quite as freely as white, red, or black oak.

Tray work shows it to be a favorite food, as a good proportion of larvæ went through to the adult stage.

Bear Oak (*Quercus ilicifolia* Wang.).

As a food for gipsy-moth larvæ this is one of the most favored oaks. Not all the observers had this species in their divisions, but those that did agree as to the favorability.

In the tray work the same thing was shown, as the larvæ fed freely in all stages.

Shingle Oak (*Quercus imbricaria* Michx.).

This oak is a favored food for gipsy-moth larvæ, especially after the first stage. A good proportion of male and female moths were reared.

No field observations were made on this species.

Swamp White Oak (*Quercus bicolor* Willd.).

The feeding in the trays was not quite as free on this species as on some of the oaks, but a fair percentage of adults were reared.

The field observers do not all agree as to the favorability of the species, as some consider it the most favored oak, while others find that it is not preferred as much as other oaks.

White Oak (*Quercus alba* L.).

This species does not put out foliage until after the other oaks and other trees in the combinations have come into leaf. The larvæ feed on the swelling buds, and many desert this species for the red, black, and scarlet oaks. This accounts for the early stripping of the other species.

Tray work and field observations show that the white oak is probably the most favored food plant of the gipsy moth.

Osage Orange (*Toxylon pomiferum* [Raf.]).

Tray experiments with this species show it is not a favored food. No pupæ were obtained and but few larvæ reached the second stage.

No field observations were made.

Pear (*Pyrus communis* L.).

Pear foliage will sustain life in the gipsy-moth larvæ and carry them through to the adult, as shown by Mr. Collins's experiments at Worcester, but the larvæ and adults were very small and weak.

In the field but very little feeding has been noted on this foliage.

Persimmon (*Diospyros virginiana* L.).

This is not a favorable food plant, as but very few larvæ passed from one stage to the next stage, and growth was very slow.

No field observations.

Pitch Pine (*Pinus rigida* Mill.).

In the tray experiments no adults were obtained from larvæ started before the fourth stage, but from this stage both male and female moths were produced.

In the field the observers note feeding by the fourth, fifth, and sixth stage larvæ when pitch pine is growing with gray birch. The feeding is mostly confined to the old needles, the new growth seldom being attacked.

Red Pine (*Pinus resinosa* Ait.).

In the tray work with this species almost no feeding was observed until larvæ in the third stage were placed upon it. These, however, did not live beyond the fourth stage. The feeding was done by eating notches in the old needles.

In the field, larvæ were seen to feed upon red pine from the third to the sixth stages. In the last three stages they sometimes cause severe stripping.

Scotch Pine (*Pinus sylvestris* L.).

Tray experiments started with first-stage larvæ on this species failed to produce second-stage larvæ. Those started with second-stage produced sixth-stage larvæ, when many died from disease. The feeding was slow until the new growth expanded, after which they fed freely.

Mr. Proctor has noted practically the same thing in the field.

Gray Pine (*Pinus banksiana* Lamb.).

First-stage larvæ started on this foliage in the trays failed to go beyond the second stage. Trays started with larvæ in the third stage produced both male and female pupæ. Feeding was fairly free on the foliage after the first stage.

No field observations were made on this pine.

Western White Pine (*Pinus monticola* Dougl.).

First-stage larvæ supplied with this foliage failed to reach the second stage, but second-stage larvæ fed and a good number of male moths were produced. The feeding after the first stage was quite free, and this food seems to be more favored than the white pine.

No field observations were made on this pine.

White Pine (*Pinus strobus* L.).

Tray experiments show that first-stage larvæ can not feed to any extent upon the foliage and do not pass into the second stage. Mr. Collins succeeded in rearing adults from second-stage larvæ at Worcester on white pine.

In the field, where the pine is clear or in mixture with hemlock, feeding did not begin before the third or fourth stages. When the pine is mixed with gray birch or with any of the oaks, first and second stage larvæ were observed feeding to a slight extent.

The larva begins feeding near the base of the needle and eats through until the larger part falls to the ground. Other needles are attacked in the same way, so that a tree may be stripped in a very short time. (Pl. VI.)

Beach Plum (*Prunus maritima* Wang.).

Beach plum is not a particularly favored food plant. First-stage larvæ died before completing the third stage, and those started in the third stage produced male moths only. They fed but little, grew very slowly, and the pupæ were of small size.

Mr. Kennedy observed larvæ in the first, second, and third stages feeding upon this foliage to a slight extent in the field.

American Aspen (*Populus tremuloides* Michx.).

Although this species can not be placed in the class with oak, apple, willow, etc., in favorability, yet it will support the larvæ from time of hatching to pupation, and will produce fairly vigorous pupæ. The male moths developed from experiments when larvæ were started in the first stage.

Feeding was observed in the field by all stages, and in some cases complete defoliation resulted.

Balm-of-Gilead (*Populus balsamifera* L.).

In the trays the food withered badly, and although first-stage larvæ developed full-grown larvæ and moths they were undersized.

In the field the writer has observed very large sixth-stage larvæ feeding on this poplar, and large adults resulted.

Large-toothed Aspen (*Populus grandidentata* Michx.).

No adults were obtained from the trays started with first-stage larvæ on this species, as the last caterpillar died in the fifth stage. The larvæ fed freely up to the fourth stage, when feeding fell off and they died rapidly of disease.

In the field much the same observations were made, but the larvæ were exceptionally large and some moths were produced.

Lombardy Poplar (*Populus nigra* var. *italica* Moench).

No adults were obtained from this species either at Worcester or at Melrose Highlands, but at the former laboratory larvæ in the fifth stage developed in trays started in the first stage. Feeding was quite free on this species, but the larvæ died rapidly of disease.

No field observations were made.

Silver Poplar (*Populus alba* L.)

Both at Worcester and Melrose Highlands the larvæ started in the first stage on this foliage all died by the time they reached the fifth stage. They fed quite freely, but died rapidly of disease.

This species is not favored by the gipsy moth as are the other poplars.

Privet (*Ligustrum vulgare* L.)

Very few larvæ started in any stage on this foliage reached the succeeding stage.

Mr. Schaffner reports slight feeding by second, third, and fourth stage larvæ. It is an unfavored species.

Raspberry (*Rubus* sp.).

Several observers have records of feeding on this plant. Most of these are of larvæ in the first stages. Complete defoliation occasionally results.

Pasture Rose (*Rosa virginiana* Mill.).

A large percentage of adults were reared from trays started with first-stage larvæ fed upon this foliage. Heavy feeding occurs in all stages.

Records of field observations show that the larvæ feed freely in all stages when the infestation is fairly heavy and stripping has been noted.

Wild Sarsaparilla (*Aralia nudicaulis* L.).

Sarsaparilla is a plant which is very common in some localities. No feeding has been found on its foliage by the gipsy-moth larvæ.

SASSAFRAS (*Sassafras sassafras* [L.] Karst.).

A few male moths were produced in trays started with first-stage larvæ on this foliage. Feeding was fairly heavy in all stages. This foliage was very hard to keep in a fresh state and the trays had to be changed frequently.

Field observers have recorded feeding in all stages and in some instances defoliation.

SERVICE-BERRY (*Amelanchier canadensis* [L.] Medic.).

This is a very favorable food plant as the tray experiments and the observations in the field show. The trays produced a good percentage of males and females. The larvæ grew rapidly and were of large size.

Field observers record the feeding of the larvæ in all stages and in some cases a complete defoliation.

SKUNK CABBAGE (*Spathyema fœtida* [L.] Raf.).

Mr. Kennedy found fourth and fifth stage larvœ feeding upon this species, and they continued into the sixth stage. Many of the leaves were badly eaten.

BLACK SPRUCE (*Picea mariana* [Mill.] B.S.P.).

No field observations were made on this species.

In the trays, first-stage larvæ were reared to adults on this foliage. During the first stage, growth was very slow and many died of starvation, but in the second stage feeding increased and continued to increase with each successive stage. The larvæ in the last stages were large and fed ravenously.

NORWAY SPRUCE (*Picea abies* [L.] Karst.).

From trays started with third-stage larvæ, adult moths were reared. Larvæ in all the lower stages died before reaching the next stage. In the later stages feeding was rapid, but in the first three stages the larvæ fed very little and growth was very slow.

RED SPRUCE (*Picea rubens* Sargent).

Trays started with first-stage larvæ on this foliage did not produce second-stage larvæ; when started with second-stage, male moths were produced only. In the first stage no feeding could be found on the foliage, and in the next stages feeding and growth were slow. In the last stages, however, the larvæ fed ravenously and growth was much faster.

WHITE SPRUCE (*Picea canadensis* (Mill.) B.S.P.).

The second stage produced a small percentage of male moths, and no females with larvæ started in trays on this foliage. Those started in the first stage died before reaching the second stage. In the later stages feeding was fairly heavy and growth was rapid. It is about the same in favorability as red spruce.

MOUNTAIN SUMAC (*Rhus copallina* L.).

This is one of the most favorable foods for all stages of the larvæ. A good percentage of males and females were reared from first-stage larvæ in the trays and growth was rapid.

All stages have been observed feeding upon it in the field, and defoliation has been noted repeatedly.

Scarlet Sumac (*Rhus glabra* L.)

This is another favorable species, and the larvæ grew to very large size. The first stage began feeding on the swelling buds by eating a small hole through the scales, and as the milky sap began to flow the larvæ fed upon it. They did not move about very much, but grew rapidly.

Feeding has been observed by all stages in the field.

Staghorn Sumac (*Rhus hirta* [L.] Sudw.).

This is not as favorable a species as the two foregoing. The larvæ do not grow as large. They will, however, develop from the first stage, but are badly attacked by disease.

All stages feed upon it in the field.

Red Gum (*Liquidambar styraciflua* L.).

This species ranks high as a favored food plant. Larvæ fed freely in all stages and grew rapidly. In the last two stages, however, they were badly affected by disease.

No field observations are available.

Sweet Pepperbush (*Clethra alnifolia* L.).

Field records show very slight feeding by all stages of the larvæ that have dropped from the overhanging trees, but they soon moved to other food.

In the trays no adults were obtained by starting any stage on this foliage until the fifth stage was reached, and then males were produced. It is a very unfavored food plant.

Sycamore (*Platanus occidentalis* L.).

Very few field records have been obtained on this species, although the second and third stages have been seen feeding very slightly on it.

In the trays the foliage was apparently very distasteful to them, and there was but little feeding and growth. Third-stage larvæ were reared to a few male moths. It is an unfavored species.

Tulip Tree (*Liriodendron tulipifera* L.).

Each successive stage was tried in the trays containing this foliage, both at Worcester and Melrose Highlands, but none reached the adult stage until experiments were begun with fifth-stage caterpillars. Scarcely any feeding was observed after the bud scales and blossoms dropped.

No field observations were made.

Black Gum (*Nyssa sylvatica* Marsh).

In the trays adults were reared from second-stage larvæ on this foliage, but all were males. In the first stage but very little feeding could be found on the leaves, and the larvæ did not reach the second stage.

In the field all stages were observed feeding upon the foliage, but no bad stripping was noted until the later stages.

Maple-leaved Arrowwood (*Viburnum acerifolium* L.).

This viburnum is not favored by the gipsy-moth larvæ in any stage, as shown by the field observations and the tray work.

In the trays none reached the adult stage, and nearly all the larvæ died in the stage in which the experiment was started.

In the field many larvæ in all stages were noted upon the foliage, having dropped from the overshadowing trees, but very little feeding was seen.

Arrowwood (*Viburnum dentatum* L.).

This foliage is somewhat more favorable as a food for gipsy-moth larvæ, as those started in the second stage reached the fifth stage, but no pupæ were obtained.

In the field but few observers had opportunity to obtain notes on this species. They have made record of slight feeding in nearly all stages.

Sweet Viburnum (*Viburnum lentago* L.).

The foliage of *lentago* is more readily eaten by gipsy-moth larvæ than the foregoing species. A few larvæ started in the early stages passed into the next stage, and male adults were obtained from trays started with fourth-stage larvæ. Growth was very slow and all were of small size.

No field observations were made on this species.

Cranberry Tree (*Viburnum opulus* L.).

Field observations show slight feeding by the larvæ in nearly all stages.

No tray experiments were conducted with this species.

Appalachian Tea (*Viburnum cassinoides* L.).

No pupæ were obtained from experiments with this species in the trays. The first-stage larvæ died after reaching the third and fourth stages, and the second-stage experiments were closed in the fifth and sixth stages.

In the field no feeding was observed except a few small notches in the leaves.

Black Walnut (*Juglans nigra* L.).

Tray experiments started with first-stage larvæ produced fifth-stage larvæ before they finally died. In the earlier stages very little feeding was done, but it increased considerably in the later stages. It is not a favorable food plant.

No field observations were made.

White Willow (*Salix alba* L.).

This is among the most-favored food plants for the gipsy-moth larvæ. In the trays a good number of adults of both sexes were obtained.

In the field all stages were observed feeding on the foliage, and large larvæ, adults, and egg masses were produced.

Glaucous Willow (*Salix discolor* Muhl.).

This species is also a favored food plant. In the trays a good number of adults were obtained from first-stage larvæ, which grew rapidly and were of large size.

No field observations were made.

BAY-LEAVED WILLOW (*Salix pentandra* L.).

From trays started with first-stage larvæ only fourth-stage larvæ were produced before they all died. No adults were obtained until fifth-stage larvæ were started. The foliage was rather distasteful to them and growth was slow.

No field observations were made on this species.

SANDBAR WILLOW (*Salix interior* Rowlee).

Not as favored as the first two species, but more favored than the bay-leaved willow. Trays started with third-stage larvæ produced both male and female moths.

No field observations were made on this willow.

WITCH-HAZEL (*Hamamelis virginiana* L.).

From the field came reports of the feeding of gipsy-moth larvæ in all stages upon this foliage, but probably more freely in the first stages.

In the trays, adults were reared from first-stage larvæ, which fed steadily in all stages.

The results given indicate in a general way the susceptibility of the species concerned to gipsy-moth attack.

There is in some cases, at least, considerable variation in susceptibility of different trees of the same species.

During the summer of 1912 foliage from two willow trees (*Salix alba* L.) were tested in trays at Melrose Highlands. They were growing side by side on lowland near a brook and both were in vigorous condition. First-stage gipsy-moth larvæ were placed in trays on the foliage of each tree.

Those supplied with the foliage of one tree fed normally, grew rapidly, and in due time developed into large adults. The other lot grew very slowly and the larvæ were very small and small adults developed. Nearly three times as many eggs were secured from the first lot as from the second. All the larvæ used in the experiment hatched from the same egg cluster.

In 1913 foliage from the same trees and larvæ hatched from the eggs of the previous year were used and the results were exactly reversed.

This indicates that there is variation in results with the same species of tree, but in this case it was not constant. A number of experiments along this line are contemplated.

COMBINATION-TRAY EXPERIMENTS.

Several series have been conducted to determine feeding preferences of gipsy-moth larvæ when two species of foliage were supplied in the same tray. In deciding the combination of species to be used it was thought best to place in the trays species that are usually found growing together in the field.

The results given below have been compared with the results with the same food plants growing in the open in so far as this data is available.

Spreckled Alder and Willow.

Larvæ fed on both species, but appeared to prefer alder in all stages. After the foliage on alder was nearly all eaten the larvæ attacked the willow.

More adults were reared from these trays than from either alder or willow when fed alone. The larvæ grew steadily and attained large size.

In the field both alder and willow, when growing together, are defoliated if the infestation is heavy. The alder is usually stripped first.

American Beech and Chestnut.

Larvæ fed freely on the beech in the first two and last two stages. In the first stage there was no feeding on chestnut, and during the second stage the feeding was light, increasing to free in the third and fourth. After the fourth stage feeding decreased on chestnut. Preference for beech was noted except in third and fourth stages.

Larvæ grew to medium size and a fair percentage reached the adult stage.

American Beech and Red Oak.

Both of these foods were eaten freely throughout the experiment. Oak was a decided favorite in the first five stages. In the sixth stage feeding decreased, as the larvæ preferred the more tender leaves of the beech. The larvæ grew rapidly and were of large size. A good percentage reached the adult stage.

In the field the larvæ fed on the beech in the first two stages, then changed to the oak, where they fed until the last stage, when they returned to the beech.

American Beech and Sugar Maple.

Both these food plants were fed upon freely until the fifth stage, then moderately. A slight but continued decrease was noted on maple from the beginning of the fifth stage to the closing of the trays. Very little preference was observed in the first four stages.

A few larvæ reached the adult stage.

Black Birch and Witch Hazel.

There was no feeding on the birch during the first stage and but very little in the second and third. In the fourth and fifth stages the larvæ preferred the birch. The larvæ fed freely on witch hazel in the early stages. The caterpillars were small and reproduction resulted from this experiment.

Gray Birch and Chestnut.

There was no feeding on the chestnut during the first stage, but a steady increase was noted thereafter. Feeding was constant on the gray birch in all stages.

The larvæ grew slowly and were of small size and but few reached the adult stage.

Gray Birch and White Pine.

The larvæ fed freely in all stages on gray birch, but none at all on the pine in the first stage. The feeding on the latter species gradually increased until, in the last stages, they fed as well on this foliage as on the birch. They grew well and attained normal size and several reached the adult stage.

In the field in areas having this combination, the larvæ fed on the birch during the first three stages, when they attacked the pines. These were defoliated in many cases in the last three stages. The prevalence of wilt in the field often exerts a powerful influence in preventing complete defoliation of pine when it is grown in this combination.

Gray Birch and Red Spruce.

During the first stage all of the feeding was on the gray birch. There was a slight increase in feeding on the spruce in the later stages until the last two, when it diminished on the spruce.

The larvæ were rather small in size and grew slowly. A few reached the adult stage.

Paper Birch and Hemlock.

The larvæ fed freely on the paper birch in all stages. No feeding was noted on hemlock in the first stage, light in the second, and increasing during the third, and continuing moderate until the trays were closed. The larvæ showed a preference for birch in all stages, grew steadily to large size, and a large number of male and female moths developed.

Paper Birch and Sugar Maple.

The sugar maple in combination with this species is a favorable food. The larvæ fed upon it freely from the first to the fifth stages. During the fifth and sixth stages it was eaten more moderately. Birch was eaten freely at all times, although preferred in the later stages. Both species were eaten equally in the earlier stages.

The larvæ were of medium size and several reached the adult stage.

Paper Birch and Large-toothed Aspen.

Both of these foods are favorable. Except in the first stage, when the poplar was preferred, the larvæ fed with the same degree of freedom upon each. They grew steadily in the first stage, but more rapidly in the remaining stages, and attained average size. Several developed into adults.

Paper Birch and Red Spruce.

Larvæ fed freely on the birch in all stages, but did not feed on the spruce in the first stage. Feeding increased from the beginning of the second stage to the end of the fifth. Medium-sized larvæ resulted, from which several adults developed.

Paper Birch and Witch-hazel.

The larvæ fed freely on both food plants, with slight preference for witch-hazel until near the end of the experiment, when birch was eaten more freely.

Large larvæ resulted, from which several adults developed.

YELLOW BIRCH AND HEMLOCK.

Larvæ fed on the birch freely in the first four stages and more moderately in the latter stages. No feeding occurred on hemlock in the first and second stages. It was slight in the third and continued light in the remaining stages.

Larvæ grew rather slowly and were of small size and a few changed to adults.

YELLOW BIRCH AND RED MAPLE.

Larvæ fed more freely on birch than on maple, and the same proportionate feeding was maintained throughout the experiment. They were of small size and were badly attacked by disease. A small number reached the adult stage.

YELLOW BIRCH AND SUGAR MAPLE.

The larvæ fed moderately on both food plants, with a slight preference for the birch at times. They grew slowly and were of moderate size. A few males and females were obtained.

YELLOW BIRCH AND WITCH-HAZEL.

There was moderate feeding on both these food plants, but at times some preference was shown for witch-hazel. Growth was rather slow and the larvæ attained moderate size. A few males resulted.

LOW BLUBERRY AND WHITE PINE.

This is the most unfavorable of the blueberries. Feeding was very light in the early stages and increased later, but at no time was this plant eaten freely. There was no feeding on pine in the first three stages. It was light in the fourth and increased in the later stages. Larvæ grew slowly in the early stages, but much more rapidly later, and reached medium size. Only males were obtained.

In a single location in the field the blueberry was very slightly eaten by first-stage larvæ, but no feeding was noted by the later stages. The infestation was light and no defoliation resulted to either the blueberry or pine.

TALL BLUEBERRY AND WHITE PINE.

The feeding on blueberry by the first and second stage was light and there was great variation in the rapidity of growth. In the remaining stages feeding was free. Pine was not eaten in the first two stages. In the other stages it was fed upon slightly, but not freely. The larvæ grew quite rapidly and reached medium size. Adults of both sexes were obtained.

BLUEBERRY AND WHITE PINE.

This blueberry is the most favored of the blueberries, and larvæ fed freely upon it in all stages. Pine was not eaten at all in the first two stages, but feeding increased in the later stages, when it was often eaten from choice. The larvæ grew rapidly and attained average size, and males and females developed.

Field reports show nearly complete stripping of the blueberry, but almost no injury being done to the pines.

SOUTHERN WHITE CEDAR AND RED MAPLE.

Maple feeding was very light in the first stage; a gradual increase in the ensuing stages, which was never more than moderate. Cedar was not eaten in any stage even when the maple was in a withered condition. The growth of the larvæ varied greatly in this experiment.

In Middleboro, Mass., a large area in a swamp where these species predominate has been under observation for several years. During some seasons both the maples and the cedars have been defoliated, the latter by the large larvæ.

The small amount of undergrowth and the few other species of trees are unfavored food for gipsy-moth larvæ, and in this case practically all the feeding has been confined to the two species under discussion. This field record furnishes information which is quite contradictory to the laboratory experiments, although such evidence is exceptional.

AMERICAN HORNBEAM AND RED OAK.

Feeding was continuous in all stages on the oak, but was very slight on the hornbeam in the first two stages, but later was much greater. A decided preference for oak was shown in all stages. The larvæ grew steadily and attained large size. A good percentage reached the adult stage.

HOPHORNBEAM AND RED OAK.

The larvæ fed freely in all stages on the oak, and the feeding increased from slight at the start to moderately free on hornbeam at the close of the experiment. Larvæ grew rapidly and attained large size and a good percentage reached the adult stage.

AMERICAN LINDEN AND RED MAPLE.

The larvæ fed moderately on the maple throughout the experiment. Linden feeding was moderate in the first stage, falling off slightly in the second and third, and moderate in the remaining stages. The larvæ were of good size and a fair percentage of adults was obtained.

ELM AND WHITE PINE.

None of the first-stage larvæ started on these food plants passed beyond the third stage. They fed only on the elm and were of very small size. Those started in the third stage produced male and female moths. They fed slowly on these foods, and grew accordingly.

In the field there has apparently been a steady decrease in the infestation, the pines being eaten by the large larvæ.

HEMLOCK AND AMERICAN LINDEN.

Larvæ fed freely on linden in all stages and very slightly on hemlock in the second stage. Feeding increased on the latter species in each successive stage. The larvæ attained moderate size, and a few adults were reared.

HEMLOCK AND SUGAR MAPLE.

There was no feeding on the hemlock during the first stage, but it increased gradually from the second to the sixth stage. Feeding was moderate on maple during the whole experiment. The larvæ reached medium size, and a few adults of both sexes were obtained.

Hemlock and Witch-hazel.

The larvæ fed freely in all stages on the witch-hazel, but none at all on the hemlock in the first stage; feeding increased gradually, and in the three last stages hemlock foliage was eaten freely.

The larvæ were of good size and produced both male and female moths.

Chestnut and Red Maple.

No feeding was apparent on the chestnut during the first and second stages, and it was moderate in the remaining stages. Feeding on maple was moderate in all stages. The larvæ were below average size, grew slowly, and only males developed.

In the field similar results have been observed.

Chestnut and Black Oak.

The larvæ fed freely on both food plants, except in the first stage, when they attacked oak exclusively. They grew steadily, attained large size, and adults were reared.

Field observations indicate that these species are freely eaten when growing in the same locality.

Chestnut and Chestnut Oak.

The oak was fed upon freely in all stages, but the chestnut was eaten moderately in all stages except the first. Growth was slow and the larvæ died before pupating.

Chestnut and White Pine.

Larvæ started in the first stage died in the third stage or earlier. Those that molted once were very small and puny, while those started in the third stage produced a few male moths. Both plants were eaten quite freely in the last stages.

Similar results have been noted in the field.

American Linden and Red Oak.

The larvæ fed lightly on the linden in the first few stages, and, although the feeding increased slightly in the later stages, it was never excessive. Oak was preferred and was eaten freely in all stages. The larvæ developed rapidly, were of average size, and several moths were reared.

In the field this combination furnishes very favorable food for the gipsy moth.

Red Maple and Witch-hazel.

The larvæ fed freely on both food plants in the first two stages, but from the end of second stage to the close of the experiment a preference was shown for witch-hazel.

The larvæ grew rather slowly and but few adults were obtained.

White Pine and Witch-hazel.

The larvæ fed moderately on witch-hazel in all stages, but none on pine during the first two stages. Later the feeding increased steadily to the end of the experiment.

The larvæ were of small size and but few adults were reared.

Poplar and Red Spruce.

The larvæ fed freely on the poplar in all stages, but very slightly on the spruce, no feeding being noted in the first two stages. They grew steadily and to fairly large size, and a small number reached the adult stage.

CLASSIFICATION OF FOOD PLANTS.

As a result of the experiments with single food plants and combinations, it is possible to draw up a classification of the trees and shrubs tested as regards their susceptibility to attack by the gipsy moth.

They have been arranged in the following classes:

Class I. Species that are favored food for the gipsy moth.

Class II. Species that are favored food for the gipsy moth after the early larval stages.

Class III. Species that are not particularly favored, but upon which a small proportion of the gipsy-moth larvæ may develop.

Class IV. Species that are unfavored food for the gipsy moth.

Class I.—*Species that are favored food for the gipsy-moth larvæ.*

Alder, Spreckled.
Apple.
Ash, Mountain.
Aspen, American.
Aspen, Large-toothed.
Balm-of-Gilead.
Beech, American.
Birch, Gray.
Birch, Paper.
Birch, Red.
Blueberry (V. *angustifolium*).
Box Elder.
Gum, Red.
Hawthorn.
Hazelnut.
Hazelnut, Beaked.
Larch, American.
Larch, European.
Linden, American.
Linden, European.
Oak, Black.
Oak, Rock Chestnut.
Oak, Dwarf Chestnut.
Oak, Bur.
Oak, Pin.
Oak, Post.
Oak, Red.
Oak, Scarlet.
Oak, Bear.
Oak, Shingle.
Oak, Swamp White.
Oak, White.
Poplar, Lombardy.
Rose, Pasture.
Service-berry.
Sumac, Mountain.
Sumac, Scarlet.
Sumac, Staghorn.
Willow, White.
Willow, Glaucous.
Willow, Sandbar.
Witch-hazel.

Class II.—*Species that are favored food for gipsy-moth larvæ after the earlier larval stages.*

Chestnut.
Hemlock.
Pine, Pitch.
Pine, Red.
Pine, Scotch.
Pine, Jack.
Pine, Western White.
Pine, White.
Plum, Beach.
Spruce, Black.
Spruce, Norway.
Spruce, Red.
Spruce, White.

CLASS III.—*Species that are not particularly favored but upon which a small proportion of the gipsy-moth larvæ may develop.*

Barberry, European.
Bayberry.
Birch, Black.
Birch, Yellow.
Blueberry, Low.
Blueberry, Tall.
Cherry, Sweet.
Cherry, Wild Black.
Cherry, Wild Red.
Chokeberry.
Choke Cherry.
Cottonwood.
Cranberry, American.
Elm, American.
Elm, European.
Elm, Slippery.
Fern, Sweet.
Gale, Sweet.
Gum, Black.
Hickory, Bitternut.
Hickory, Mockernut.
Hickory, Pignut.
Hickory, Shagbark.
Hornbeam, American.
Hophornbeam.
Maple, Norway.
Maple, Red.
Maple, Silver.
Maple, Sugar.
Pear.
Poplar, Silver.
Sassafras.

CLASS IV.—*Species that are unfavored food for gipsy-moth larvæ.*

Arbor Vitæ.
Arrowwood.
Arrowwood, Maple-leaved.
Ash, Black.
Ash, Blue.
Ash, Red.
Ash, White.
Azalea, White and Flame.
Balsam, Fir.
Blackberry, High.
Blue-flag, Larger.
Butternut.
Catalpa, Hardy.
Cedar, Red.
Cedar, Southern White.
Cornus.
Cranberry-tree.
Currant, Red.
Cypress, Bald.
Dangleberry.
Dock, Narrow.
Dogwood, Flowering.
Elder, American.
Eubotrys, Swamp.
Feverbush.
Grape.
Greenbrier.
Hackberry.
Hardhack, Pink.
Hardhack, White.
Holly, American White.
Honeysuckle, Bush.
Huckleberry, Highbush.
Inkberry.
Ivy, Poison.
Juniper, Common.
Kentucky Coffee-tree.
Laurel, Mountain.
Laurel, Sheep.
Locust, Black.
Locust, Honey.
Maple, Mountain.
Maple, Striped.
Mulberry, Red.
Mulberry, White.
Osage Orange.
Osier, Red.
Pepperbush.
Persimmon.
Privet.
Raspberry.
Sarsaparilla.
Skunk Cabbage.
Spice-bush.
Sweetbrier.
Sweet Pepper-bush.
Sycamore.
Tea, Appalachian.
Tulip-tree.
Viburnum, Sweet.
Walnut, Black.
Willow, Bay-leaved.
Winterberry, Smooth.

In arranging the foregoing classes it was not easy in all cases to assign a food plant according to this arbitrary classification. A number of species such as the poplars and hickories belong near the border line of Classes I and II, and they have been rated in the list which seems most appropriate. In general it can be said that whenever any of the trees or shrubs in Class IV are growing together no injury from gipsy-moth attack need be feared, and the same is true of Class II, or a combination of Classes II and IV. In case any of the species given in Class III are present there is a slight chance of injury resulting, but for practical purposes no difficulty is likely to be experienced by an owner so long as the species given in Class I are not present in his woodland or on his private grounds.

THE FOREST PROBLEM.

An examination of these classes, however, shows that the species noted in Class I are at present the dominant species in the woodlands in the area now infested with the gipsy moth. The oaks and birches predominate over much of this area, and this increases the difficulty of remedying the situation.

It will be noted that most of the species of high commercial value are included in Classes I and II. In arranging combinations which will resist moth attack it is necessary to consider the soil and other conditions suitable for their successful growth and to endeavor to bring about replacements with the least possible expenditure of money.

The encouragement of coniferous growth is to be commended provided the Class I trees can be eliminated. Experimental work with different stands of forest growth is being conducted by Mr. G. E. Clement, of the Bureau of Entomology, and practical advice to owners conveying the best methods of handling their wooded areas is being furnished.

It should be noted in examining the foregoing lists that, in addition to forest trees and shrubs, plants of much importance to horticulture and for ornamental and city planting are included. The problem is therefore broader than that of managing forests, as horticultural and shade-tree management should be adopted so that the least injury will result from the moth and that the least expense in controlling it will be necessary.

RECOMMENDATIONS FOR ORCHARD PRACTICE.

Among the horticultural crops most likely to be affected by the gipsy moth is the apple.

In moderate infestations the gipsy moth can be controlled by spraying with arsenate of lead, used at the rate of 10 pounds to 100

gallons of water. It should be applied as soon as the trees come into full leaf and will assist materially in controlling the codling moth. Improved methods of management and care of the trees will do much to decrease the danger from this pest. Hollow trees should be filled or cut, and all rubbish that will furnish convenient quarters in which the moths may deposit their eggs should be cleaned up and burned.

If the orchard infestation is serious, creosoting egg clusters and banding the trees with tanglefoot may be necessary.

During the past year a number of cases of severe injury to cranberries have been observed. This was caused by feeding of the caterpillars on the tender growth and cutting off the fruit buds and blossoms, which resulted in a serious decrease in the yield.

It is probable that this insect will not increase in sufficient numbers in cranberry bogs to kill the vines, and it has, therefore, been considered as able to survive on this plant (Class III). The money loss on account of diminution in yield is likely to be serious.

THE CITY PROBLEM.

On home grounds, in cities and parks, or on street or shade trees, this problem requires the expenditure of large sums of money if species favorable for the development of gipsy-moth caterpillars are to remain. Not only must the insect be reduced, so that injury to the trees will not result, but the caterpillar nuisance must be abated, particularly in the residential sections.

When future plantings are made, species should be selected which will not require a constant expenditure of money in order to keep them free from the moths. The lists given will furnish a guide in this respect.

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OPPORTUNITIES FOR PURCHASING NATIONAL FOREST TIMBER.

The National Forests contain nearly 590 billion feet of merchantable stumpage. The mature timber, which constitutes a large part of the total stand, is for sale. The more accessible bodies may be purchased in blocks of practically any desired size up to 75 million feet. Less accessible stumpage which requires a large investment for the construction of transportation facilities may be purchased in larger quantities of sufficient size to justify the investment in improvements. Applications up to one billion feet will be approved if the investment required necessitates the purchase of a body of that size under one contract.

The procedure for purchasing National Forest timber is extremely simple. Applications specifying the amount, species, and general location desired may be sent to the offices of the Forest Service at Washington, D. C.; Missoula, Mont.; Denver, Colo.; Albuquerque, N. Mex.; Ogden, Utah; San Francisco, Cal.; and Portland, Oreg. Advertisement at a fixed minimum price is required by law for at least 30 days. The timber is then awarded to the highest bidder and the sale completed by execution of the contract stating the amount and location of the stumpage, the stumpage rates, and the conditions under which the timber shall be removed.

The contract requirements have been prepared by practical lumbermen and perfected by the experience gained in the administration of several thousand sales. They are adapted to the local conditions as to topography, size of the timber, and logging methods. That they are eminently practical is demonstrated by the fact that some 600 million feet are cut each year under these requirements by lumbermen all over the West.

Sufficient time is permitted for the removal of the amount purchased under local conditions of logging and manufacture. The time is gauged, however, to require continuous operation at a reasonable rate and does not permit the holding of stumpage for speculative increases in value. Contracts exceeding five years in duration provide for a readjustment of stumpage prices at not less than three-year intervals beginning with the commencement of the cutting period and exclusive of any preliminary period allowed for the construction of improvements. These readjustments are based upon average lumber values during the three years preceding the date of readjustment as compared with the average lumber values upon which the initial stumpage prices are based. The timber to be cut is designated by the forest officers. Either clean cutting, or partial cutting taking 70 to 80 per cent of the stumpage, is employed, depending upon the character of the timber and the best methods of securing new forest growth. Simple precautions are required to protect the uncut timber and young growth, and the disposal of slash by burning, either with or without piling, is necessary. These requirements may increase the cost of logging from 50 to 75 cents a thousand feet over the usual cost on private holdings. The difference is always considered in appraising the value of the stumpage. Furthermore, an operator who buys National Forest timber has to make practically no investment at the outset for his stumpage, has no carrying charges for interest or taxes, and incurs practically no fire risk. He is required simply to pay for the timber as it is removed in advance deposits, which represent usually but the value of two months' cut.

These are obvious advantages, particularly when extended over an operation of 10 or 15 years. As private stumpage is cut out in many of the old lumbering centers, operators will find, in the timber on the National Forests, new opportunities for manufacture under advantageous conditions.

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